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W. L. Abbott

President W. S. E., 1907.

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Journal of the
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VOL. XII. FEBRUARY, 1907. NO. 1.

"THE PROGRESS OF ELECTRICITY ON STEAM ROADS IN 1906."

PRESIDENTIAL ADDRESS OF BION J. ARNOLD.

Delivered at the Annual Meeting of the Society Jan. 8, 1907.

On a former occasion, in September, 1904, during the International Electrical Congress, at the joint meeting of the Institution of Electrical Engineers of Great Britain and the Amercian Institute of Electrical Engineers, as retiring president of the latter body, I spoke upon the "Electrification of Steam Railroads," and it may be of interest to quote a few paragraphs from that speech, as the predictions made at that time seem to have been fairly closely followed since.

After having referred to the early struggles of the electrical engineer in attempting to introduce electric traction in street and interurban railway service, and referring briefly to the large electrification schemes then under way, I said:

"That electricity will be generally used on our main railway terminals, and ultimately on our main through lines for passenger and freight service, I am convinced, but I do not anticipate that it will always be adopted on the ground of economy in operation, neither do I anticipate that it will come rapidly, or through the voluntary acts of the owners of steam railroads, except in special instances.

"At first the terminals will be equipped for special reasons, due either to the voluntary act on the part of the terminal companies to effect economy in operation, or to public pressure brought to bear upon the owners through an increased demand on the part of the public for better service, on the grounds that the use of the steam locomotive is objectionable in our great cities.

"Those roads which run through populous countries will either build new roads, or acquire, for their own protection, those electric railroads already built and operating in competition with them, and utilize them as feeders to their through line steam trains. Thus the steam railroad companies will gradually become interested in electric railways and eventually become practically the real owners of them. With these roads operating as feeders to the main line system and with the terminals thus equipped and the public educated to the advantages of riding in electrically equipped cars, the next step will logically be the electrical equipment of the trunk lines between the cities already having electrical terminals.

"Thus some favorably located trunk line having a sufficient density of population will feel warranted in equipping electrically, and when this is once done the other roads running between the same competing points must, sooner or later, follow, in order to hold their passenger traffic.

"This may result in temporarily relegating some roads to freight service, so long as they operate exclusively by steam, but with the increased demand on the part of the public for better and cleaner service will come a corresponding increase in passenger revenue to the roads equipped for handling it until one road after another finds it advantageous to furnish an electric passenger service.

"With the terminals and main line equipped electrically, and the desire on the part of the public for more prompt and effective freight service resembling that which is given by the steam roads in England and on the Continent, due to the great density of population, there will be developed a great high class freight service conducted in light, swiftly moving electric trains which can be quickly divided and distributed over the surface tracks of our smaller cities, or through underground systems similar to that which is now being built in Chicago. Such a system would soon prove indispensable to the public and a source of great profit to the roads as it is now getting to be to many suburban railways.

"This class of freight service would prove so large a part of the freight traffic of a road that the operation of the through freight traffic by steam locomotives, though at present cheaper, would in time, as the cost of coal increases, grow less, until those roads operating an electric passenger service would ultimately use electricity exclusively."

Previous to that time the officials of the steam railways of the country had paid but little attention to the subject of electricity, but were then beginning to realize the inroads that were being made upon their local traffic by the interurban roads. This caused the more progressive ones among them to begin to carefully investigate the claims of the advantages of electric traction, with the result that at that time there were either contemplated, or well under way, a number of important electrical installations, which could be credited to the favorable decisions of steam railway officials.

Confirming the prediction which I then made, to the effect that the steam railroads would acquire the electric roads paralleling them, I call attention to the fact that according to published reports the New York Central R. R. has since then, in addition to practically completing its great electric terminal in New York City, either purchased outright, or acquired indirectly the controlling interest in most of the interurban roads paralleling its lines between Albany and Buffalo, and the New York, New Haven & Hartford R. R. has recently acquired practically all the interurban roads which compete with it in its territory. The Erie R. R., in addition to its preparation for the electrification of its terminals in the vicinity of Jersey City, is now equipping thirty-four miles of track, extending southeast of Buffalo, thus retaining traffic which might have been taken from it by the construction of competing interurban lines.

In like manner the Pennsylvania R. R. system, in addition to the electrification of its great terminal system in the vicinity of New York, is gradually electrifying the Long Island R. R. system, which so effectually gridirons the island lying east of Manhattan Island, and known as Long Island.

The New York, New Haven & Hartford R. R. is also going to great expense in the electrification of its line from New York City to Stamford, Conn., a distance of thirty-one miles, with reasonable probability of gradual extension of electric traction over its system.

These few examples, together with the electrical operation of the great Simplon tunnel, by means of which the traveler will be carried from Switzerland into Italy without the annoyance due to the obnoxious gases emitted from the steam locomotive, are sufficiently impressive, I believe, to emphasize the correctness of the lines of development outlined by me in 1904, involving, as they do, an expenditure of approximately $100,000,000, for electrical equipment, and a collateral investment of some $300,000,000 more.

In addition to these general types there are now under construction, or contemplated construction, many special installations adopted for various reasons, such, for instance, as the Saint Clair tunnel of the Grand Trunk, extending from Port Huron, Michigan, to Sarnia, Ontario, wherein steam locomotives will soon be abandoned and trains operated electrically.

The equipment of the Cascade Division of the Great Northern, over the Cascade mountains, a distance of about 100 miles, although not yet definitely decided upon is another notable example of the contemplated application of electricity to steam roads. Its equipment would eliminate the use of steam locomotives now operating over a tortuous piece of road, and through a long and difficult tunnel.

Electrification is also contemplated upon a division of the Southern Pacific, through the Sierra Nevada mountains, for the purpose of eliminating the difficulties due to tunnel operation, and of increasing the capacity of the road, which is now limited by the size of the present steam locomotives.

Thinking that a little more specific information regarding certain important installations that have been put in operation during the past year, or are now under construction, would be of interest, I will describe some of them briefly, attempting to bring out the principal points, and eliminating detail as far as practicable:

New York Central & Hudson River R. R.: As is well known, this railroad has been engaged in the electrification of its New York terminal for about four years, and has recently put into operation, for passenger service, interurban trains running between New York City and High Bridge, a distance of about nine miles, and is now introducing electric locomotives into the terminal service for operation of its through trains between the Grand Central terminal and Croton, 35 miles, and North White Plains, on the Harlem division, 29 miles from New York. The installation will, when completed, consist of two power stations of 30,000 kw. each, and 8 sub-stations which will supply and distribute electrical energy to about 400 miles of track within a radius of 40 miles from the city of New York. An experimental track for testing the locomotives designed for this special work was equipped by the New York Central and the General Electric companies, acting jointly, and upon this track, experiments have been conducted for the past three years, with the result that the type of locomotive for through train service which is now being introduced into actual work has, by a long series of experiments, proven itself capable of doing the work for which it is intended. Of these machines, 35 are now ready for operation and will be introduced as rapidly as men can be trained to operate them. Each locomotive weighs 100 tons, has a normal capacity of 2,200 h. p. and a maximum capacity of 3,000 h. p. and will run at speeds varying from 40 to 80 miles per hour, depending upon the weight of the trains, which will vary from 250 to 900 tons. Two or more locomotives can be coupled together for heavy train service, and operated upon the multiple unit system in the same manner as the cars.

There will soon be 200 steel motor cars in service, each equipped with 400 h. p. of motor capacity, and so arranged that they can be run singly or in multiple, at will, although some are now used as trailers without motor equipments. Each motor car is 60 feet long over all, weighs 53 tons, seats 60 passengers, and is designed to run at a maximum speed of 52 miles per hour.

One power house, in which has been installed 20,000 kw. in turbo-generators and the necessary auxiliaries, is now in service, and the energy distributed to the trains by means of four sub-stations, in which are placed storage battery auxiliaries for the purpose of regulating the load upon the power stations, and for reserve capacity in case of accident to any sub-station or power station. From the sub-stations the energy is distributed to the trains by means of secondary copper feeders and an inverted, or under-contact, type of third rail.

By the adoption of electric traction the New York Central R. R. was enabled to abandon the use of steam locomotives in its Park Avenue tunnel, which has always been a source of annoyance to its patrons and of danger to the road. It has also been enabled to make extensive improvements in its terminal facilities, in the way of lowering its tracks, thereby making the viaducts leading from the western part of the city to the east side available for team traffic, thus adding greatly to the value of east side real estate. This condition of lowering the viaducts had been imposed upon the company by the City of New York before they could obtain permission to make the improvement. With this condition imposed upon it, however, the company saw fit to acquire a large amount of additional real estate on each side of the right of way, which permitted its engineers and architects to plan a much more comprehensive terminal system than had been previously possible. This terminal station will cost approximately $15,000,000 when completed, and will be built upon the double deck plan, the suburban trains entering it at the lower level, and the express trains on the upper level. The introduction of electric traction into this terminal has made it practicable for the company to expend advantageously about $65,000,000 in these terminal improvements, about $15,000,000 of which was for the electric traction portion of the equipment.

TUNNELS: Other great improvements now planned or under construction, which are made possible by the introduction of electricity, and which will enable all other steam railroads in the vicinity of New York City to enter Manhattan Island, are:

Pennsylvania R. R.: Beginning at Bergen Hill in New Jersey, about 2.7 miles from the proposed New York City station, and almost directly in line with Thirty-third street on Manhattan Island, the plans of the Pennsylvania R. R. contemplate the construction of two tunnels, each 19 feet in diameter, parallel with each other, from Bergen Hill, through the Palisades, and under the Hudson River, thence under a portion of Manhattan Island to the terminal station located between Thirty-second and Thirty-fourth streets and Seventh and Eighth avenues in New York City. From this terminal station eastward there will be four tunnels, each 23 feet in diameter, extending across the island and under the East River to the terminal in Long Island City, where the tracks will come to the surface, and connect with the extensive yards contemplated by the Pennsylvania R. R. at that point. Through these tunnels, which are about 14,000 feet in length, will be operated, by electric locomotives, all passenger service entering New York City, of the Pennsylvania R. R., and probably a large amount of freight for the distribution yard at Long Island City. The suburban trains for interurban service passing through these tunnels will be operated on the multiple unit system, and the electric locomotives, will be as in the case of the New York Central R. R., similarly operated, when it is desired to couple them together.

For the purpose of enabling the interurban and other steam roads entering Jersey City to enter the City of New York, there are now being constructed two other systems of tunnels, one under the name of the Hudson & Manhattan R. R., and the other under the name of the New York & Jersey R. R. The interests of both companies have been recently consolidated and now operate under the name of the former. The two tunnels of the Hudson & Manhattan R. R. extend from the foot of Exchange Place in Jersey City to the terminal at Church and Fulton streets on the island of Manhattan, a distance of about 9,000 feet. The tunnels of the New York & Jersey R. R. will extend from the foot of Fourteenth street in Jersey City to Morton street on Manhattan island, a distance of about 5,000 feet.

It will be noticed that the tunnels of both of these companies are considerably smaller than those of the Pennsylvania R. R. They are constructed for the purpose of feeding the present subway of the Interborough Company; consequently all cars entering these tunnels will have to be of the special small and low design now used by the Interborough Company, a misfortune which it seems impossible now to overcome, as it will effectually prevent any of the through trains of the steam roads which now terminate at Jersey City entering Manhattan island unless they come through tunnels of their own to be hereafter constructed.

In addition to the subways heretofore mentioned, to be used for the accommodation of steam railway traffic, there are to be four additional tunnels constructed under the East River, two by the New York & Long Island R. R. at Forty-second street, and two under the direction of the Rapid Transit Commission, from the present terminal of the Interborough subway, at the Battery, to Joralemon street in Brooklyn, and connecting with the subway under construction to the Flatbush terminal of the Long Island R. R.

It will thus be seen that when the present tunnels which are now under construction are completed there will be six under the Hudson River, and eight under the East River, or fourteen in all.

While certain experimental electric locomotives have been built for operation in the Pennsylvania R. R. tunnels, and it is probable that the third rail, direct current method of propulsion will be used, I do not understand that the type of locomotive or system of propulsion has been absolutely decided upon and therefore omit further details.

All cars which will operate through the tunnels of the Hudson & Manhattan Company, and the New York & Jersey Company will necessarily have to be of the type which will operate upon the direct current third rail, such as is used in the operation of the Interborough Company's subway.

NEW YORK, NEW HAVEN & HARTFORD R. R.: The decision of the New York Central R. R. to adopt electricity for its terminal, necessitated similar action on the part of the New York, New Haven & Hartford R. R., as the trains of the latter company enter the Grand Central Station over the tracks of the former company. The New York, New Haven & Hartford not having taken up the subject until some two years after the decision of the New York Central was made, and having the benefit of the development in the state of the art, decided not to adopt the direct current, third rail method of propulsion, but on the contrary adopted the single phase overhead contact method of train propulsion, and is now engaged in installing and getting ready for operation the most extensive and elaborate single phase system yet attempted, the outcome of which is being watched with great interest by railroad men.

This company is at present installing electric traction on its system between Woodlawn, (where its tracks join those of the New York Central R. R.), and Stamford, Conn., 33 miles from New York. Between Woodlawn and Stamford the road will be equipped with overhead working conductors, operating with single phase 25 cycle current at 11,000 volts. From this conductor the current will be collected by means of under-contact sliding shoes, transformed to a pressure of about 450 volts by the transformers carried upon the locomotives, and used in the motors as alternating current. Each locomotive is designed to weigh 72 tons, has a nominal capacity of 1,000 h. p. and continuous capacity of 800 h. p. and is designed to make from 26 to 45 miles per hour, with trains varying from 200 tons to 250 tons. Several of these locomotives have been delivered and are now being tried out upon the experimental track of the company; it is expected that they will go into practical service as soon as the overhead work and power station equipment of the company can be completed. The company will not at present use the multiple unit system, but will operate its suburban trains by means of these electric locomotives, 30 of which have been ordered for this service. The system will be operated from the company's power station, generating single phase current, and having a capacity sufficient to properly operate the trains. The overhead construction is divided in sections with suitable circuit breakers at the end of each section which will open automatically in case of a short circuit, or can be manually controlled by the towerman.

St. Clair Tunnel: In order to eliminate the present objections regarding the use of steam locomotives in the St. Clair tunnel of the Grand Trunk system, extending between Port Huron, Mich., and Sarnia, Ontario, the officials of that company decided a little over a year ago to adopt electrical propulsion. After due consideration, it was decided to adopt the single phase method of propulsion. This system was adopted for several reasons, the principal one being the objection to the use of the third rail in the yard of the company at each end of the tunnel, which was quite extensive, and in which much switching had to be done in making up trains before entering the tunnel. The equipment will consist of six electric locomotives, weighing 120 tons each, having a normal capacity of 1,500 h. p., capable of exerting a drawbar pull of 25,000 pounds, at a speed of 10 miles per hour, and a maximum speed for passenger train service of 35 miles per hour. They will operate with alternating single phase 25 cycle current at 3,000 volts collected from an overhead conductor by means of an under contact sliding shoe.

The power station, which is now well under construction, will contain two 1,250 kw. turbo-generators, either one of which will be capable of operating the tunnel up to its full capacity, the other being held in reserve. The decision to adopt single phase for this installation was made by the writer sometime prior to the decision of the New York, New Haven & Hartford R. R., and like it, the working of this system in this class of service will be carefully watched.

ERIE R. R.: This road has a commission organized for the purpose considering the feasibility of electrically equipping its lines, now running out of Jersey City, a total of about 250 miles, although it is contemplated that but 35 miles will be immediately equipped, viz.: the division extending from Jersey City to Greenwood Lake. In addition to its suburban lines in the vicinity of Jersey City and its terminal, the road now has under construction 34 miles of single track, known as the Rochester Division. This division lies between Rochester, N. Y. and Avon, with a branch between Avon and Mt. Morris. The single phase alternating current system will be used, having a working pressure of 11,000 volts on the overhead conductor. The energy will be secured from Niagara Falls at a pressure of 60,000 volts. Six passenger coaches, 54 feet long, and seating 56 people, will be placed in service, each car weighing about 50 tons, and equipped with four 100 h. p. motors. These cars will be capable of a maximum speed of from 45 to 50 miles per hour, and of hauling one trailer. While this extension of the Erie R. R. is short, the company has under contemplation the electrical equipment of its entire suburban service surrounding Jersey City, which will involve an expenditure of some $15,000,000. Plans are now being formulated for this expenditure.

WEST JERSEY AND SEASHORE (BRANCH PENNSYLVANIA R. R.): This is a recently electrified branch of the Pennsylvania R. R., from Camden, N. J. to Atlantic City, a distance of 65 miles. The equipment consists of a power house, 8 sub-stations, and 71 miles of duplicate high tension line. The service is ultimately to consist of three-car express trains running 60 miles per hour, on a 15 minute headway, and local service at 10 minute intervals. The equipment of this line was done in record breaking time, the site for the power house having been chosen January 17, 1906, and on July 1st two boilers were under steam with a turbine and auxiliaries running, and car service on the line. The ability to secure direct current apparatus quickly was one of the main reasons for adopting the direct current system in this case

In the sub-stations the line voltage is reduced and transformed from 33,000 volts three-phase, to 650 volts direct current. Third rail equipment was used of the Pennsylvania R. R. standard dimensions. These dimensions will satisfactorily operate with the equipment of the Long Island R. R. and the Interborough system of Manhattan Island. The rail is protected at stations and in yards. The cars for service on this line have a seating capacity of 58, are double vestibuled, and are well protected from fire risk. The cars are 55 feet 5½ inches long, and weigh, when fully equipped, 89,000 pounds, being heated and lighted electrically, and equipped with hand brakes and quick service air brakes.

SOUTHERN PACIFIC RY.: This system is making active preparations to change about 20 miles of local steam line for electric traction service. The line extends from the Ferry terminal, San Francisco, to Alameda and Oakland. The generator station is at Alameda. The electrical equipment is built for 500 volts direct current, with overhead trolley and utilizing present tracks. A year has been allowed for this work to be completed, after which time the electrification of the lines may possibly be extended. It is not the intention at present to do away with the steam locomotives, but these will be used to aid the electric service during the rush hours. It is stated that an appropriation of about $1,250,000 has been made for this work.

WEST SHORE R. R.: An important piece of equipment for electrical operation is now under construction between Utica and Syracuse, N. Y. The work in hand covers a distance of 44 miles, and the passenger train schedule provides for limited trains in each direction, making the distance from terminal to terminal in 1 hour and 22 minutes. In deciding upon the plans the relative merits of alternate current overhead equipment and third rail current equipment were carefully considered, and the decision to install the direct current system was largely determined by the general flexibility of a third rail equipment, should it become desirable to make lateral extensions, install additions, side tracks, etc.

Over certain sections of the line traffic conditions require that two additional tracks be built. These tracks will enable the passenger trains, operated by electricity at 55 and 45 miles an hour, to avoid interference with freight trains operated by steam, as fast freight trains with a schedule of about 25 miles per hour, and local freights with a schedule of about 15 miles per hour. Construction work was started on May 15, and is well under way at the present time.

Electric power will be furnished by the Hudson River Electric Power Company, which will deliver three-phase 60,000 volt current at the railway company's sub-station 7 miles west of Utica. The Hudson River company for the present will generate this current at its auxiliary steam plant in Utica, but upon the completion of its contemplated transmission lines, current will very likely be taken from the hydro-electric plants owned by the company in the eastern part of the state. There will be four sub-stations located about 10½ miles apart. These will be identical in construction and each will be equipped with two 300kw. rotaries and necessary apparatus for transforming 60,000 volt three-phase current to direct current at 600 volts for distribution to the rails.

The transmission line towers will be of steel and similar in design to those built for the Syracuse Rapid Transit R. R. There will be 391 of these towers with normal spacing of 480 feet. Most of the towers are 39 feet high, but the highest are 63 feet. The line conductors will be located at the vertices of an equilateral triangle 7 feet on a side.

The third rail construction is the Wilgus under-running protected type, this being the standard adopted by the New York Central R. R. The rail is protected for the greater part of the distance by 1¼ inch wood planks above the rail, and on both sides, and part of the line has a rail protection of indurated fibre three-sixteenths inch thick moulded to conform with the rail section. The third rail is located between the parallel tracks except where curves, or other special conditions require it to be transferred to other sides of the track. The company will operate 15 closed cars, 49 feet long over bumpers, each equipped with four 75 h. p. motors per car, with multiple unit control.

SPOKANE & INLAND RY.: This is a single-phase line between Spokane, Washington, and neighboring cities, having a total mileage of 114. The capital invested in the project is approximately $3,500,000. The service includes passenger, mail, express and carload freight. The power is purchased from the Washington Water-Power Co. and is delivered to the railway company as three-phase 60 cycle current to a frequency changing station 10 miles south of Spokane This station has four frequency changers each of nominal 1,000 h. p. capacity which convert the current to 25 cycle 2,200 volt single phase current. For transmission to the sub-stations this 2,200 volt current is stepped up to 45,000 volts and transmitted to 15 sub-stations where it is stepped down to 6,600 volts for direct connection to the trolley circuits.

The cars and locomotives operate on three different voltages at different parts of the line. In the country 6,600 volt alternating current is used and in the smaller towns 700 volt alternating current, while within the limits of Spokane 600 volt direct current is used. In the country and through the small towns a pantagraph under-running trolley is utilized while in Spokane the ordinary under-running trolley wheel is used. The passage from the alternating current to the direct current system is done by operating a commutating switch, which makes all the necessary connections, and by changing the trolley from the pantagraph to the wheel type.

The cars are equipped with four-100 h. p. alternating current motors. The locomotive uses the same type of motors but have a capacity of 150 h. p. each. Both the locomotives and coaches can be operated on the multiple unit system. The locomotives are capable of handling seven standard freight cars, fully loaded, at

30 miles per hour, on level track. This locomotive weighs 49 tons and has a length over the bumpers of 29 feet.

EUROPEAN WORK: Some recent installations may be of interest. Progress is being made on the tunnel work under the Seine for additional lines to the Paris Metropolitan Railway. The project for the tunnel under the English channel between Calais and Dover has acquired a new interest and is a subject much under discussion. The proposed tunnels would be 18 feet in diameter, the submarine portion being 24 miles in length, with aproaches six miles in length, and of course would be operated electrically. This tunnel is designed to carry the rolling stock of the principal European railroads.

The Simplon Tunnel: The new electric locomotive for use in the Simplon tunnel is of special interest as showing the latest progress in the design of a locomotive for running upon a high voltage three-phase current. The locomotives are designed to allow two normal running speeds which are obtained by the proper switching of the circuit. Power used is from 3,000 volts three-phase 15 cycle circuits and provides the two standard speeds of 25 and 40 miles per hour. They are designed to pull a total load of 440 tons including the locomotive, this condition to hold good even with reduction of line pressure as low as 2,700 volts. The principal dimensions of the locomotive are as follows:

The length over buffers is 41 feet, 8 inches; diameter of the driving wheels, 5 feet, 6 inches; total weight of locomotive 68 tons, of which the mechanical part is 37 tons and the electrical outfit 31 tons. The capacity in normal running is 900 h. p. The main controlling apparatus of the locomotive uses compressed air for operating the reversing and other switches. A trolley is mounted on the roof at each end of the locomotive and works against the overhead wire, the design of this trolley being a special feature of this locomotive. The lower parts have the form of a parallelogram which can be raised or lowered by air pressure. The upper arm which carries the trolley contact is made very short and light, and has a limited motion to either side.

CONCLUSION: From what has been said it can be seen that rapid progress is being made in the application of electricity to steam railroads. Some installations have been made on account of the economy in operation to be effected, and the increased earning capacity to be gained, while others have been made under public pressure. With the completion of the work now under construction by the New York Central R. R. and the New York, New Haven & Hartford R. R. companies the steam locomotive will disappear forever from the island of Manhattan, and its surrounding territory.

From an examination of the map of the business district of Chicago, bounded by Sixteenth street, Halsted street, Chicago avenue, and the Lake, it will be seen that 23% of this area is occupied by the tracks of steam railway companies. In view of the present state of the art of electric railroading, the right to vitiate the air of our congested districts by the emission of large quantities of carbon-dioxide from the stacks of numerous locomotives is as questionable as the right to foul the air by the stenches from our stock yards. As there is now a possibility of the removal of these yards from our midst, is it unreasonable to hope that all of the steam railroad companies, through the wise foresight of their officers, may help us to purify and beautify the city, by assisting the general movement now under way by our progressive civic bodies for this purpose? In my judgment at least one, and probably three of the companies now operating in the city of Chicago can afford to and would profit by the electrical operation of their suburban trains.

Note—During the address, a large number of lantern slide views were shown illustrating the various installations, locomotives, cars, etc., to which reference was made by the speaker.—Ed.

DESIGN OF SWING BRIDGES, FROM A MAINTENANCE STANDPOINT.

Paper by C. H. Cartlidge, April 18, 1906, and Discussion by W. H. Finley and others.

Introduction by the Publication Committee.

In all of our draw bridge literature, there is nowhere to be found, as the writer believes, a thorough discussion of the draw bridge as a *machine in use,* that is to say from the operating and maintenance standpoint. Divergent methods of construction have grown up and have been developed on different railroads and in different sections of the country. These have been tested by experience and improved from year to year; but each for the most part without any very critical comparison with other and diverse types of construction. Each railroad and each bridge company, or designer has for the most part followed its or his own line of development. The railroads do not have to build these structures themselves, and the bridge companies do not have to maintain them. One is therefore not surprised to see radical differences of opinion on nearly all important question of draw bridge design, and a full discussion of these questions from all sides and angles must therefore be of very great value.

These papers and discussions were presented on April 18th and May 16th, 1906, and excited more than usual interest. The material proved to be very valuable, coming as it did from railroad engineers and designers, in all parts of the country; but the nature of the discussions made it impossible to give adequate presentation of the subject without considerable rearrangement and revision. It was also felt that material of this kind, in order to be of practical value should be classified by subject, and it was therefore decided to revise the entire discussion under certain headings, to eliminate, so far as possible, the repetitions and inaccuracies incident to verbal reports, and to ask each contributor to revise and amplify his remarks as carefully and thoroughly as possible.

With this end in view the following letter was sent to each contributor.

"Gentlemen:

On the 18th of April, 1906, and the 16th of May following, you took part in the presentation and discussion of a paper on the design of swing spans from a maintenance standpoint. A great deal of very interesting and important matter was brought out in these discussions, but the character of the discussion was such as to make a verbatim report rather hard to follow, and of little value as a reference. Under the circumstances the Publication Committee, and such of those who discussed the paper as have been consulted, feel that the en-

> tire discussion should be rearranged and classified, so that each important question connected with the design and maintenance of swing bridges will be covered by the various authors completely and in a connected manner.
>
> We are intending to subdivide the discussion under the following headings:
>
> 1st.—Character of turn table,—center bearing, rim bearing, combined center and rim bearing.
> 2d.—The construction of turn table (all types, including machinery for hand operation.)
> 3d.—Different types of end lift.
> 4th.—Power operation.
> 5th.—General questions of construction.
>
> Suggestions are asked from you as to the adequacy of this classification, and you are also requested to look over the draft of discussion handed you herewith and go over your portion of it carefully, so as to express your ideas on the various questions involved, whether the actual discussion in the Society's Rooms covers the ground or not.
>
> Kindly give this matter your very prompt attention, as the matter must be put in shape for an early issue of the Journal."

The matter in the following pages is therefore presented more as a symposium. than in the regular form of "paper and discussion" and the Committee sincerely hopes that the resulting clearness of statement and arrangement will justify the time and labor devoted to this work.

Andrews Allen,
Chariman, Publication Committee.

C. H. Cartlidge, M. W. S. E.

Presented April 18, 1906.

In looking over a number of plans for swing bridges by different engineers, the writer has been struck by the absence of provision for certain functions, relatively unimportant, yet affecting both the ease and cost of maintenance. A few of these have been noted, and in the present paper will be touched upon briefly. No attempt will be made to discuss the question of design of draw spans in a broad sense, either from a mathematical or structural standpoint. The few points presented are simply some of those which have arisen during the writer's experience, and they are touched upon in order to invite discussion of their value.

In the designs which are described here there is little which is orginal, but the details have been selected because of their fitness for their duty, as demonstrated by our experience in maintaining these and other structures.

A study of various plans is a profitable preliminary to any designing, as it is often to be found that existing conditions have been satisfactorily met. By going over them all, eliminating such details as seem unsuitable, and selecting the good ones, it is possible to make of the composite, a really good design.

A choice, however, must often be made between two or more apparently equally good details, and this is true in the case of the sort of center to be employed.

In swing spans, the choice of the type of bearing to be used lies between three, each of which has its advocates. These may be classified as follows:

1. Center Bearing.
2. Rim Bearing.
3. Combined Center and Rim Bearing.

(1) A center bearing turntable, in which all loads are carried to the pivot, was at one time the most popular. As in this case there is no drum, with its complicated stresses and doubtful distribution of the loads on the wheels, the comparative certainty of the mathematical work appealed to designers. Some provision has to be made, however, against tipping the span while being turned, and trucks running on a circular track must be connected to the drums by girders of considerable strength, so that the theoretical simplicity is not realized.

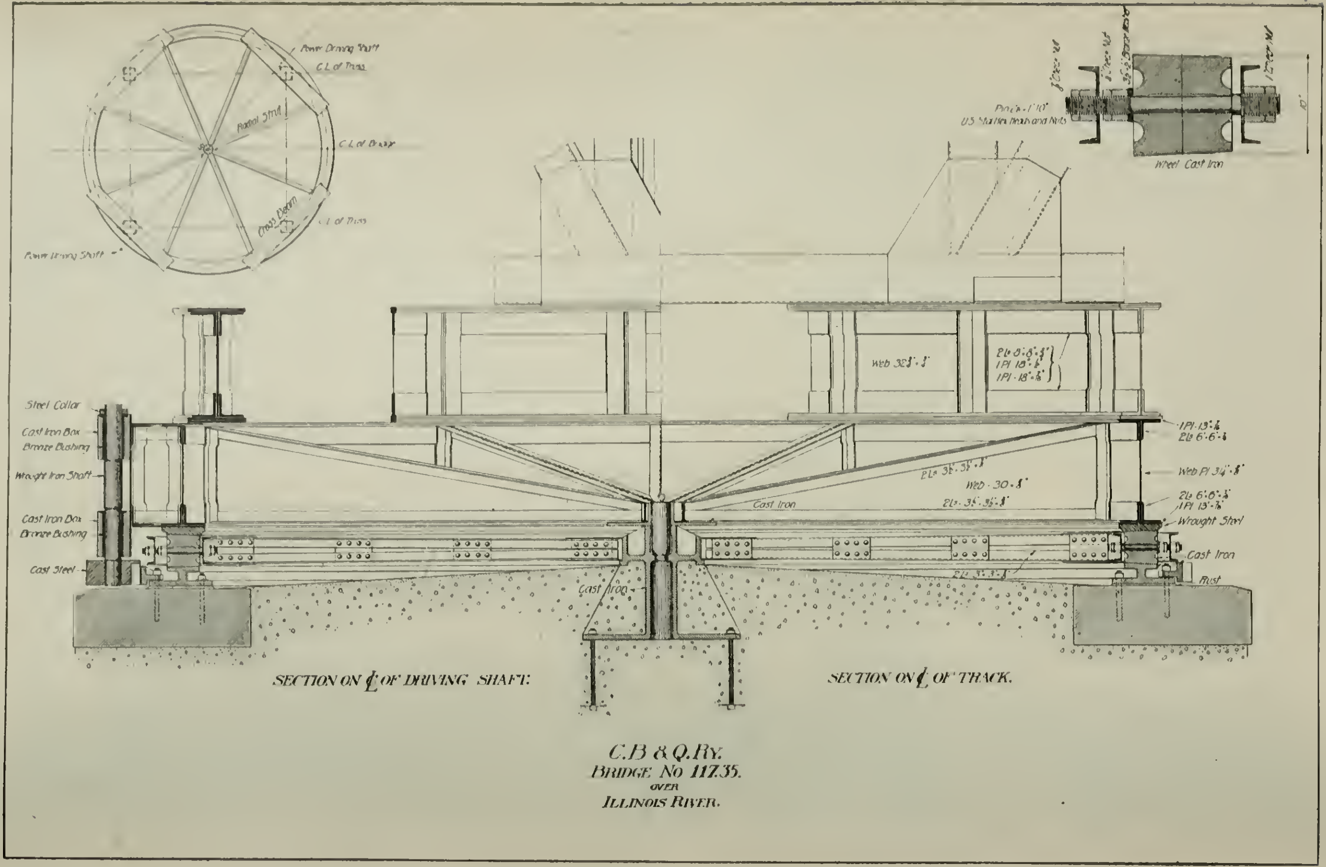
One great advantage which accrues to a center bearing is that of ease of turning, and while everything is new and in adjustment this advantage is realized. Should there be any excessive wear, however, this is soon lost, and it is necessary to make bearing areas as large as practicable, in order to prevent such wear.

(2) The complications, referred to above, involved by the use of a rim bearing center, are more theoretical than actual, as experience with spans of widely varying length has demonstrated. The drum should of course be deep enough to avoid deflection, and if there is head room to permit this, a rim bearing will be found extremely satisfactory, especially if the span is of moderate length. For spans up to 300 ft. the writer usually employs this style of center, and one such is shown in Figure 1. This is the rim bearing center for the draw span of the Illinois River Bridge, at Beardstown, Ill.

The points seeming to the writer most worthy of note as affecting the cost of maintenance will be mentioned in turn.

You will note the depth to which the pivot castings are sunk into the concrete piers. This is an important detail, and this treatment obviates a good deal of trouble from loosened anchor bolts and consequent loosening of the pivot. Much difficulty of this sort has been encountered in the past. A rigid pivot, such as this anchorage provides, permits much less chattering and vibration when the bridge is turning than one which will allow of any play whatever.

Most old draw spans were designed with adjustable radial rods, one end of each rod carrying a wheel. These rods were usually



C.B & Q. Ry.
BRIDGE No 117.35.
OVER
ILLINOIS RIVER.

Fig. 1.

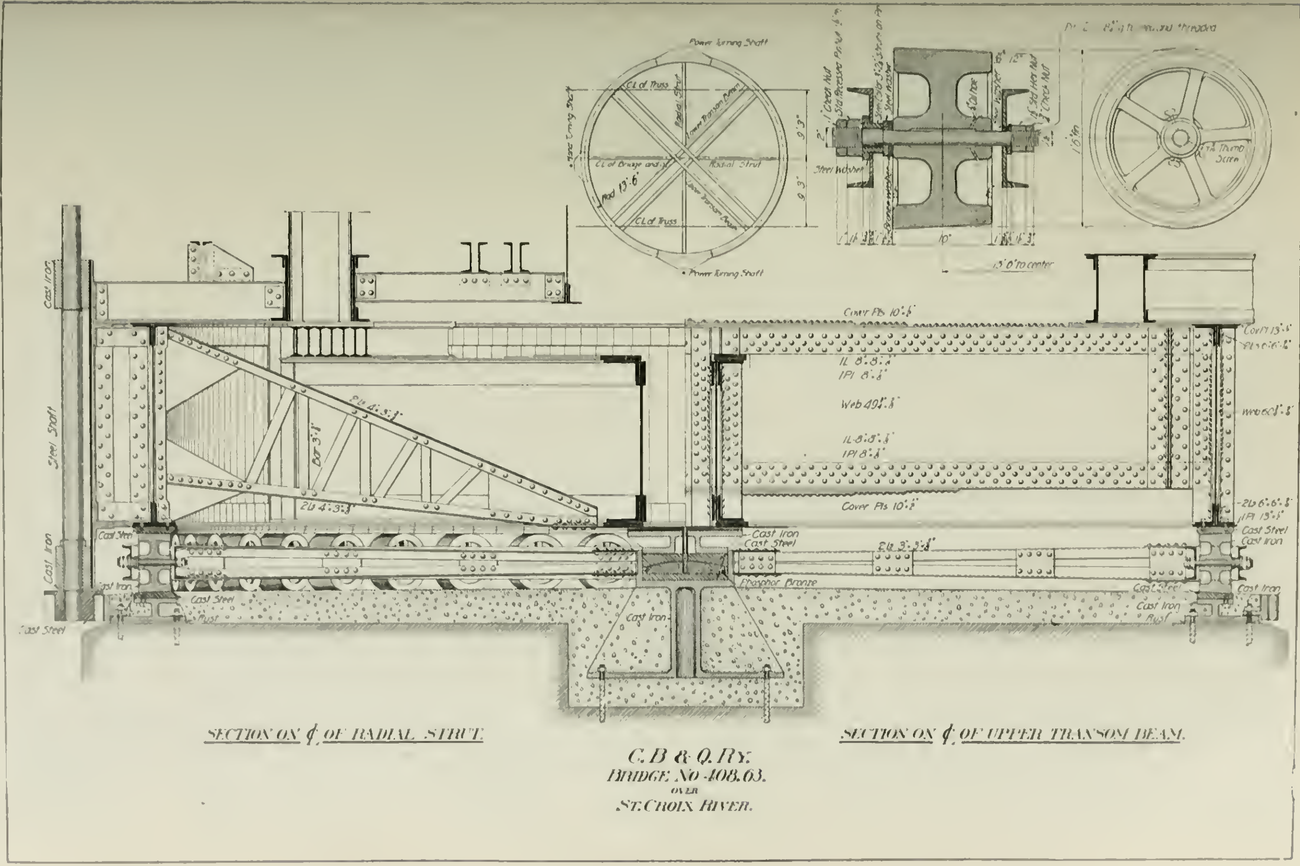

Power Turning Shaft
Hand Turning Shaft
CL of Truss
Radial Strut
Lower Transom Beam
CL of Bridge and ℄
Radial Strut
Rod 13'6"
Upper Transom Beam
CL of Truss
9'3"
9'3"
Power Turning Shaft
1" Check Nut
Std. Recessed Pin Nut
Steel Washer
Steel Washer
Bronze Washer
Oil hole
Std. Hex Nut
Check Nut
2"
10"
13'0" to center
16'4"
Thumb Screw
Cover Pls 10"
Cov Pl 13"
Pls 6"
1L 8"
1Pl 8"
Web 49"
Web 60"
1L 8"
1Pl 8"
Cover Pls 10"
2Ls 6"
1Pl 13"
Cast Steel
Cast Iron
Cast Iron
Cast Steel
2Ls 3"
Phosphor Bronze
Cast Steel
Cast Iron
Cast Iron
Rust
Cast Iron
Steel Shaft
Cast Iron
Cast Steel
2Ls 4"
Bar 3"
2Ls 4"
Cast Steel
Cast Iron
Cast Iron
Cast Steel
Rust
Cast Iron
SECTION ON ℄ OF RADIAL STRUT.
SECTION ON ℄ OF UPPER TRANSOM BEAM.
C. B & Q. Ry.
BRIDGE No 408.63.
OVER
ST. CROIX RIVER.

Fig. 2.

held to spacing by light bars or sometimes light channels. There have been several cases in which the binding of the nuts on the outer ends of the rods has caused them to revolve with the wheels. and the other ends being held, the rods were badly twisted, some even being twisted in two. This trouble is entirely obviated by the use of a stiff ring, of channels held to gage by batten plates between the wheels, and having stiff radial arms to the pivot. The wheels run on axles. adjustable radially, with tool steel washers to avoid danger of the nuts being turned by friction and thus altering the adjustment. In later designs these washers have been made of bronze, with a greater reduction of this danger.

The simplicity of this turntable is very apparent when looking at the actual bridge, and for spans of about the size and weight of this one is perfectly satisfactory.

Since this bridge, Fig. 1. has been in service, there has been no difficulty with it, of any character. The only expense has been for oiling and keeping the pivot pier clean.

The writer's experience with center bearing draw spans has been such as to prejudice him against them for spans of any magnitude. It seems to be difficult at any reasonable cost to proportion the pivot bearing so that it will not wear, and any wear on a pivot bearing is expensive to repair. On one draw the wearing away of the bronze bearing in the pivot allowed the upper and lower castings to rub, making the turning of the draw a very noisy operation, while the few wheels provided to steady the span while turning were overloaded and cut the circular track badly.

The design which. for ease of operation and repair and low maintenance cost has proven to be quite satisfactory, is shown in the next drawing, Fig. 2. This is the center for the single track draw span over the St. Croix River. near Prescott, Wis. The span is 368 ft. and is designed to carry a uniform train load of 7,000 lbs. per foot. so that it is quite heavy. The beams bearing on the center casting are designed to carry one half the dead load to the casting. The adjustment of the load is by means of shim plates between the beams and the top of the pivot. The adjustment is made during erection, the beams first being allowed to rest on the rollers with the center casting clear. The center is then jacked up until the drum just clears the wheels. After noting the amount of the lift. shims to half its amount are put in and the beams lowered to permanent bearing. This is of course only an approximate method.

Attention is directed to the depth to which the center bearing is sunk into the masonry in this design also.

A number of spans have been built with center bearings of cone shaped rollers. The writer has had to maintain some of these, though at this writing all have been replaced.

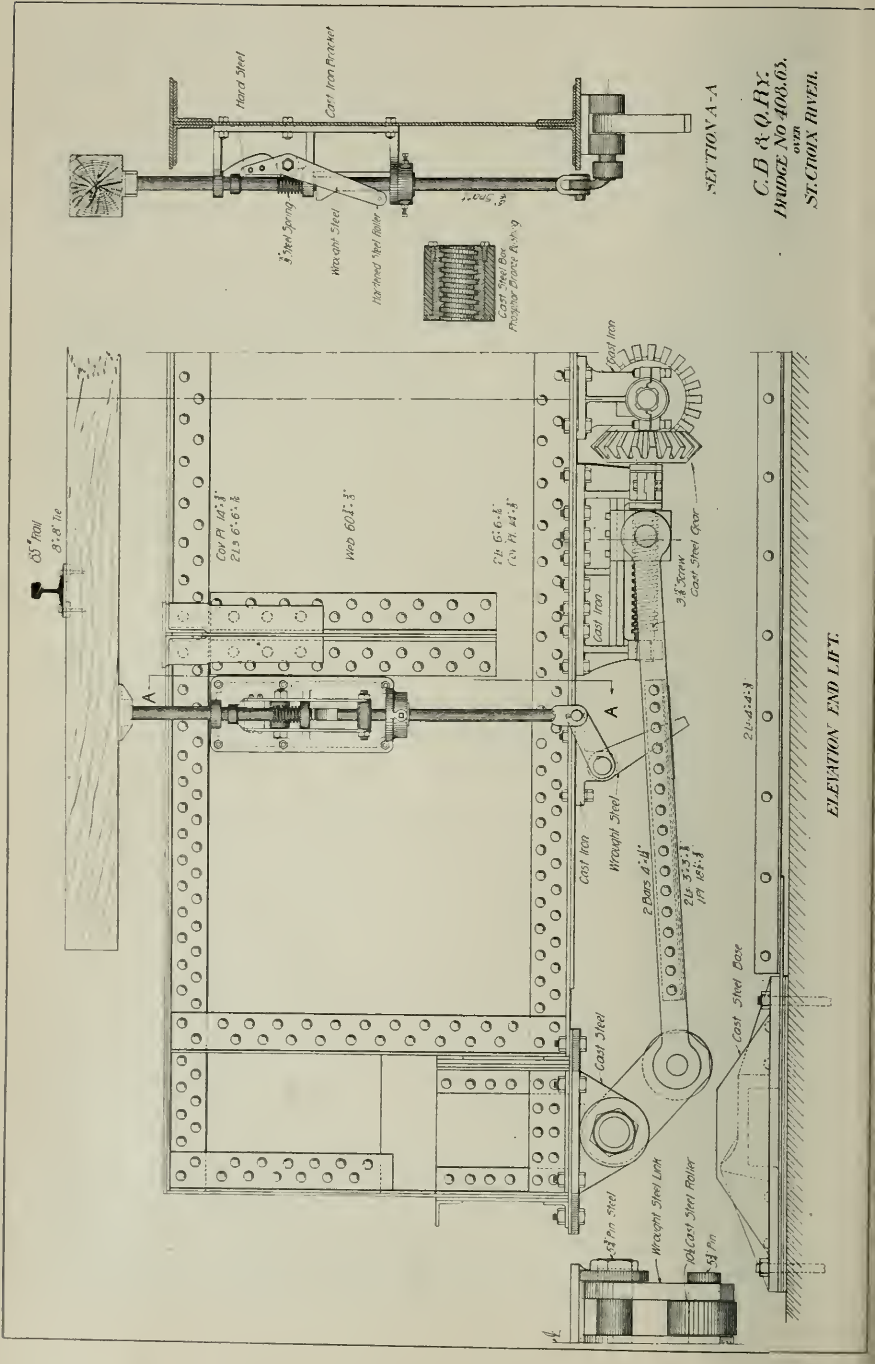
The experience gained in the maintenance of these conical roller centers has led to the design shown. involving lenses of steel and bronze. The cone rollers were found to wear unevenly, some of them never rolled, but slid on the bearings, although they were oiled and cleaned yearly. It is hardly necessary to point out the expensive nature of the work of taking out and cleaning these rollers. The bearing adopted has no such defect. The resistance to turning is theoretically greater, but it is a simple matter to provide the necessary additional horsepower in the engine, and at a cost much less for capital and interest than the cost of maintenance of the cone roller bearings, to say nothing of the freedom from trouble.

An oil hole is drilled through the saddle casting and the two upper lenses; a pipe running to the bridge floor is tapped into this and is capped with an oil cup, so that the bearing is constantly lubricated. As all parts of the bearing are made to a close working fit no dust can enter. These provisions for lubrication and for protection against dust are quite as important to the maintenance department as any structural provision, and they are points most frequently overlooked. In this connection the three oil holes in the hubs of the rim-wheels are worth notice, as it is possible for the oiler to lubricate the axle no matter what the position of the wheel. As it is generally very much easier *not* to oil these wheels, than to do so, it is just as well to make the process as easy as possible.

The next drawing, Fig. 3, shows the details of the end lifting device for the St. Croix bridge. This is typical of practically all such devices in use on the C., B. & Q. Ry., but it differs in some few details from the first ones built of similar design.

The necessity for an efficient end lifting apparatus is apparent to every designer and the writer's experience with wedges has led him to the conclusion that the difficulties in the way of getting adequate lift with them are too great. It is very likely that if the power of the engines had been greater there would have been no great difficulty, but it was found in practice that when the pedestals were set at an elevation required to give the desired lift the wedges could not be driven. When they were adjusted to such a height as to allow of the wedges being driven, there was no reaction with a heavy train on the opposite arm of the span. The end lift shown has not failed to provide all required uplift and as its construction is such that its maximum efficiency of thrust is reached at the time of maximum load it is very easily handled. It is, of course, not in the least degree novel, but there are some features which are, so far as the writer is aware.

In the earlier forms of end-lifts the nut traveling on the horizontal screw was of steel, unbushed. At times of heavy duty, when a warn day caused the draw to deflect, this nut would sometimes become welded to the screw. Bushing with phosphor bronze has stopped this entirely. The vertical links which are under the chord end are beveled on the lower end to engage a similarly bev-



SECTION A-A

C.B.& Q.RY.
BRIDGE No 408.63.
over
ST. CROIX RIVER.

ELEVATION END LIFT.

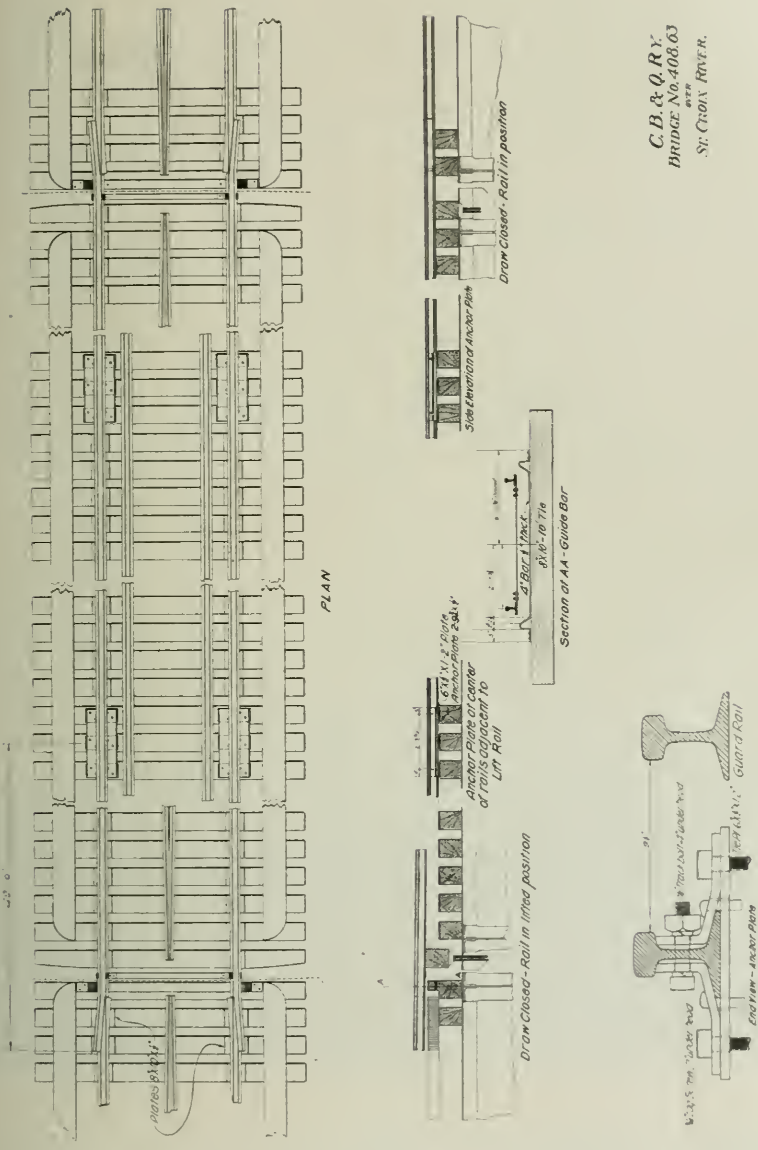

PLAN
Draw Closed - Rail in lifted position
Anchor Plate at center of rails adjacent to Lift Rail
Side Elevation at Anchor Plate
Draw Closed - Rail in position
Section at AA - Guide Bar
4" Bar 1" thick
8x10"-10' Tie
C.B.&Q.R.Y.
BRIDGE No. 408.63
over
St. Croix River.
Guard Rail
End View - Anchor Plate

Fig. 31.

eled surface on the casting. When they are in position they form a positive lock for the span and serve to bring it to exact line,—a very difficult thing to do by means of the turning gear alone. The upper surfaces of these links bear against the steel casting which is riveted to the lower chord. As the upper pinholes in the links are made considerably larger than the pin the latter is not called upon to take any load while the lift is in action.

The connection of the two base castings by plates and angles is very necessary as it relieves the anchor bolts of the horizontal components of the lifting thrust.

The rail-lift illustrated has, the writer believes, first employed by the late Geo. S. Morrison. The lifting rod is cut, and the lower half free to follow the lever down as the span is lifted, until the operation is nearly complete, when a projection on the lower rod trips the trigger holding the upper half, with the result that the rails fall with a jar sufficient to drive them into place without further adjustment. The action of the combined apparatus, in first centering the ends, then lifting them and finally dropping the rails, is found to work admirably. While the rail-lift looks somewhat complicated there has been no difficulty with any which we have in use.

A general view of this St. Croix River Bridge—reproduced from a photograph is shown in Fig. 4.

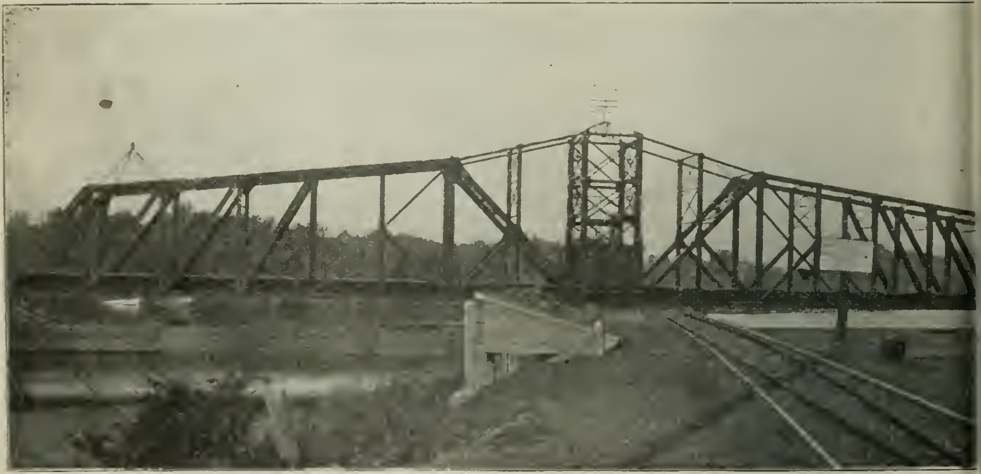


Fig. 4.

There are certain details of design of the structural part of draw spans which affect the question of maintenance to a considerable extent, and of which little or no mention is made in text books. It may be laid down as a general rule, that there should be absolutely no adjustable members in the trusses. All parts subject to complete reversal of stress, should be stiff members and have, as far as possible, riveted connections. No pin connections should be employed save for eye bar members. This is particularly true of the connection between the end of the lower chord and the foot of the end post. The constant reversal of stress at this point, due to lifting and lowering the ends of the draw, very soon develops serious wear on pins and pin holes. With a properly designed riveted connection, no play being possible, there will be no difficulty.

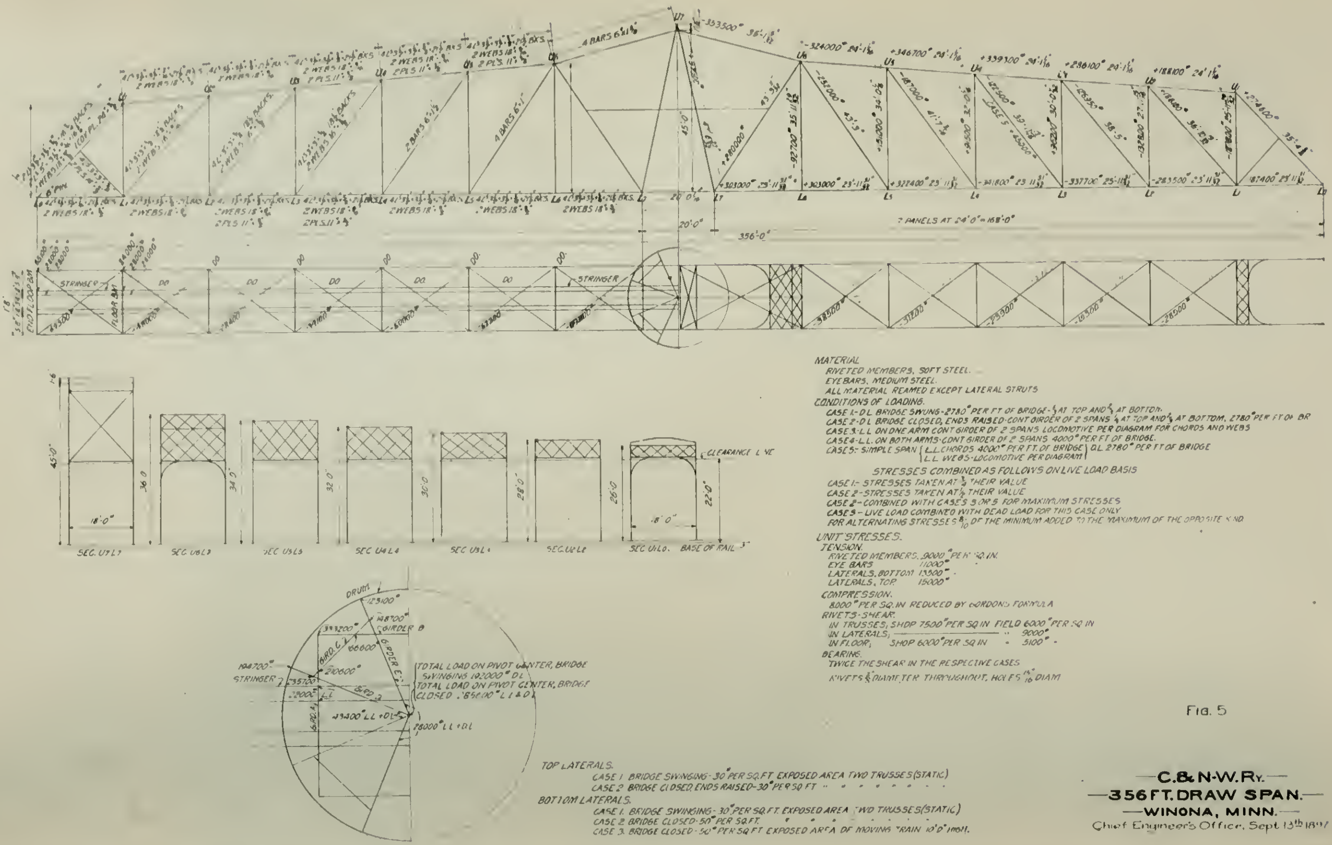
In draw span design, perhaps to a greater degree than in any other, simplicity and rigidity are the prime requisites to economical operation and maintenance.

DISCUSSION.

NO. I. CHARACTER OF TURNTABLE; CENTER BEARING, RIM BEARING, COMBINED CENTER AND RIM BEARING.

Mr. W. H. Finley: Consideration of the turntable brings up the question of center bearing, rim bearing, or combined center and rim bearing. All of these methods have been used from the earliest times and each still has its advocates. From my own experience I prefer the combined center and rim bearing, where the distribution of pressure is positive between the two. In Fig. 5 is indicated the method employed in distributing the pressure between the center and rim in the 356 ft. single track swing span over the Mississippi river at Winona, Minn., built in 1889. One objection to the method shown, is the large center pier that is required. In this particular case the center pier was in existence, and advantage of this fact was taken in designing the drum

In Fig. 6. is an elevation and plan of a 230 ft. double track swing span carrying the Chicago and North-Western Railway over Kinnickinnic river, Milwaukee, and was built in the winter of 1898-9. The turntable in this case is a square box (A-B) with corner girders (C). This avoids the circular drum and permits a minimum diameter of center pier; it also admits of designing a satisfactory turntable with much less distance from the base of rail to masonry than is possible with a circular drum. Part of the weight is carried to the center pivot by the cross girder (D-D). These girders were jacked up at the center until a definite amount of weight was transferred from the truss points, and the shims were inserted between the cross girders and the center pivot bearing. This is somewhat similar to the method obtained by Mr. Cartlidge in his St. Croix river swing span. Although the box form of turntable used on the Kinnickinnic swing span is somewhat novel, yet it has



TOTAL LOAD ON PIVOT CENTER, BRIDGE SWINGING 192000" DL
TOTAL LOAD ON PIVOT CENTER, BRIDGE CLOSED 856000" L L & D L

MATERIAL.
RIVETED MEMBERS, SOFT STEEL.
EYE BARS, MEDIUM STEEL.
ALL MATERIAL REAMED EXCEPT LATERAL STRUTS

CONDITIONS OF LOADING.
CASE 1 - D L BRIDGE SWUNG - 2780" PER FT OF BRIDGE - ¼ AT TOP AND ¾ AT BOTTOM.
CASE 2 - D L BRIDGE CLOSED, ENDS RAISED - CONT GIRDER OF 2 SPANS ¼ AT TOP AND ¾ AT BOTTOM, 2780" PER FT OF BR
CASE 3 - L L ON ONE ARM CONT GIRDER OF 2 SPANS LOCOMOTIVE PER DIAGRAM FOR CHORDS AND WEBS
CASE 4 - L L. ON BOTH ARMS - CONT GIRDER OF 2 SPANS 4000" PER FT OF BRIDGE.
CASE 5 - SIMPLE SPAN { L.L. CHORDS 4000" PER FT. OF BRIDGE / L L WEBS - LOCOMOTIVE PER DIAGRAM } DL 2780" PER FT OF BRIDGE

STRESSES COMBINED AS FOLLOWS ON LIVE LOAD BASIS
CASE 1 - STRESSES TAKEN AT ¾ THEIR VALUE
CASE 2 - STRESSES TAKEN AT ½ THEIR VALUE
CASE 2 - COMBINED WITH CASES 3 OR 5 FOR MAXIMUM STRESSES
CASE 5 - LIVE LOAD COMBINED WITH DEAD LOAD FOR THIS CASE ONLY
FOR ALTERNATING STRESSES 8/10 OF THE MINIMUM ADDED TO THE MAXIMUM OF THE OPPOSITE KIND

UNIT STRESSES.
TENSION.
RIVETED MEMBERS, 9000" PER SQ. IN.
EYE BARS 11000"
LATERALS, BOTTOM 13500"
LATERALS, TOP 15000"
COMPRESSION.
8000" PER SQ. IN REDUCED BY GORDONS FORMULA
RIVETS - SHEAR.
IN TRUSSES, SHOP 7500" PER SQ IN FIELD 6000" PER SQ IN
IN LATERALS, ——— " 9000"
IN FLOOR, SHOP 6000" PER SQ IN " 5100"
BEARING.
TWICE THE SHEAR IN THE RESPECTIVE CASES
RIVETS ⅞" DIAMETER THROUGHOUT, HOLES 15/16" DIAM

TOP LATERALS.
CASE 1 BRIDGE SWINGING - 30" PER SQ. FT. EXPOSED AREA TWO TRUSSES (STATIC)
CASE 2 BRIDGE CLOSED, ENDS RAISED - 30" PER SQ FT " " " " " " "
BOTTOM LATERALS.
CASE 1. BRIDGE SWINGING - 30" PER SQ. FT. EXPOSED AREA TWO TRUSSES (STATIC)
CASE 2 BRIDGE CLOSED - 50" PER SQ. FT. " " " " " "
CASE 3. BRIDGE CLOSED - 50" PER SQ FT EXPOSED AREA OF MOVING TRAIN 10'0" HIGH.

—C. & N-W. Ry.—
—356 FT. DRAW SPAN.—
—WINONA, MINN.—
Chief Engineer's Office, Sept 13th 1897

Fig. 5.

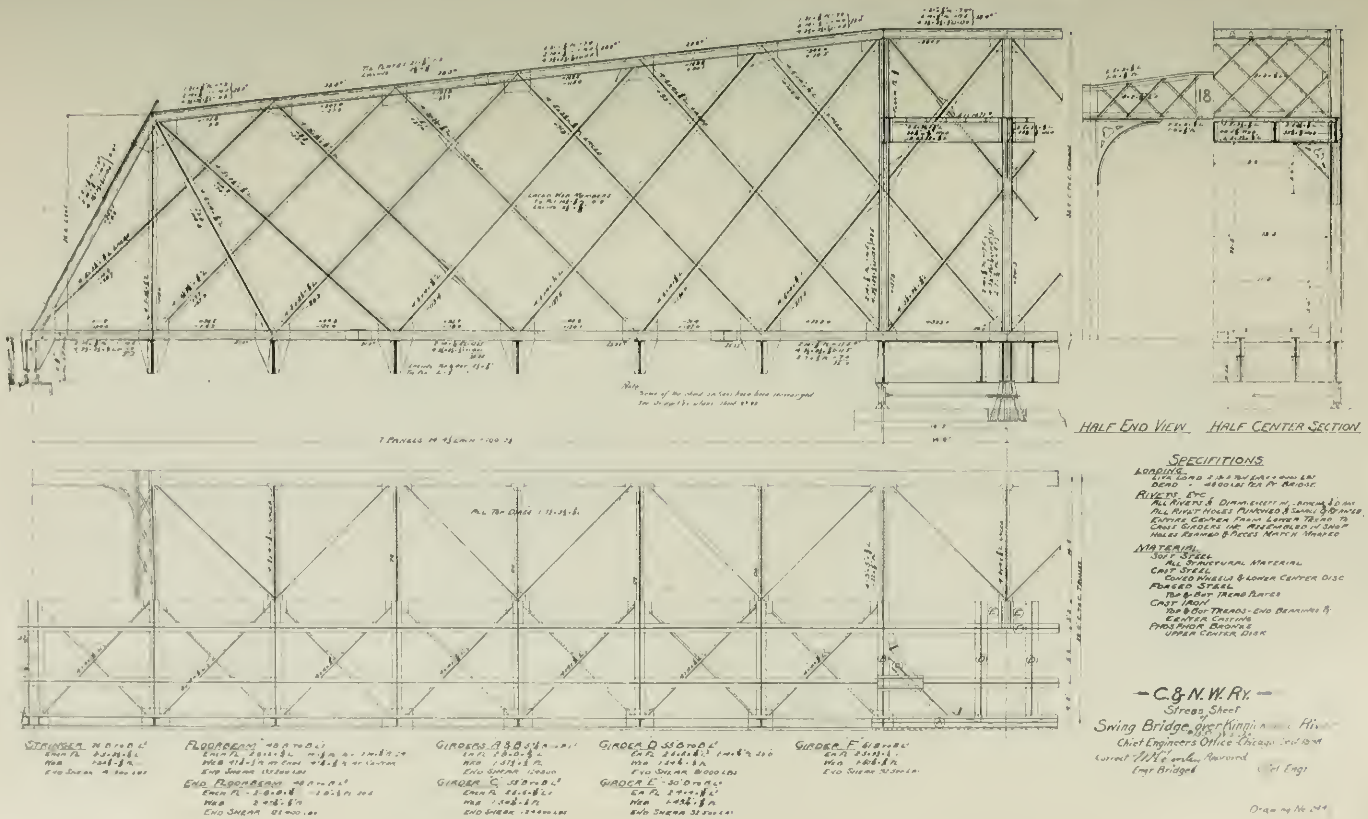

Lacen Web Members
7 Panels
All Top Diags
HALF END VIEW
HALF CENTER SECTION
18.
SPECIFITIONS
LOADING
LIVE LOAD
DEAD - 4600 LBS PER FT BRIDGE
RIVETS ETC
ALL RIVETS DIAM. EXCEPT
ALL RIVET HOLES PUNCHED & SMALL & REAMED
ENTIRE CENTER FROM LOWER TREAD TO
CROSS GIRDERS INC. ASSEMBLED IN SHOP
HOLES REAMED & PIECES MATCH MARKED
MATERIAL
SOFT STEEL
ALL STRUCTURAL MATERIAL
CAST STEEL
CONED WHEELS & LOWER CENTER DISC
FORGED STEEL
TOP & BOT TREAD PLATES
CAST IRON
TOP & BOT TREADS - END BEARINGS &
CENTER CASTING
PHOSPHOR BRONZE
UPPER CENTER DISK
— C. & N. W. RY. —
Stress Sheet
of
Swing Bridge over Kinni River
Chief Engineers Office Chicago
Correct
Approved
Engr Bridges
Chief Engr
Drawing No.
STRINGER
EACH FL
WEB
END SHEAR
FLOORBEAM
EACH FL
WEB AT ENDS AT CENTER
END SHEAR
END FLOORBEAM
EACH FL
WEB
END SHEAR
GIRDERS A & B
EA FL
WEB
END SHEAR
GIRDER C
EACH FL
WEB
END SHEAR
GIRDER D
EA FL
WEB
END SHEAR 81000 LBS
GIRDER E
EA FL
WEB
END SHEAR
GIRDER F
EA FL
WEB
END SHEAR
I
J
E
D

Fig. 6.

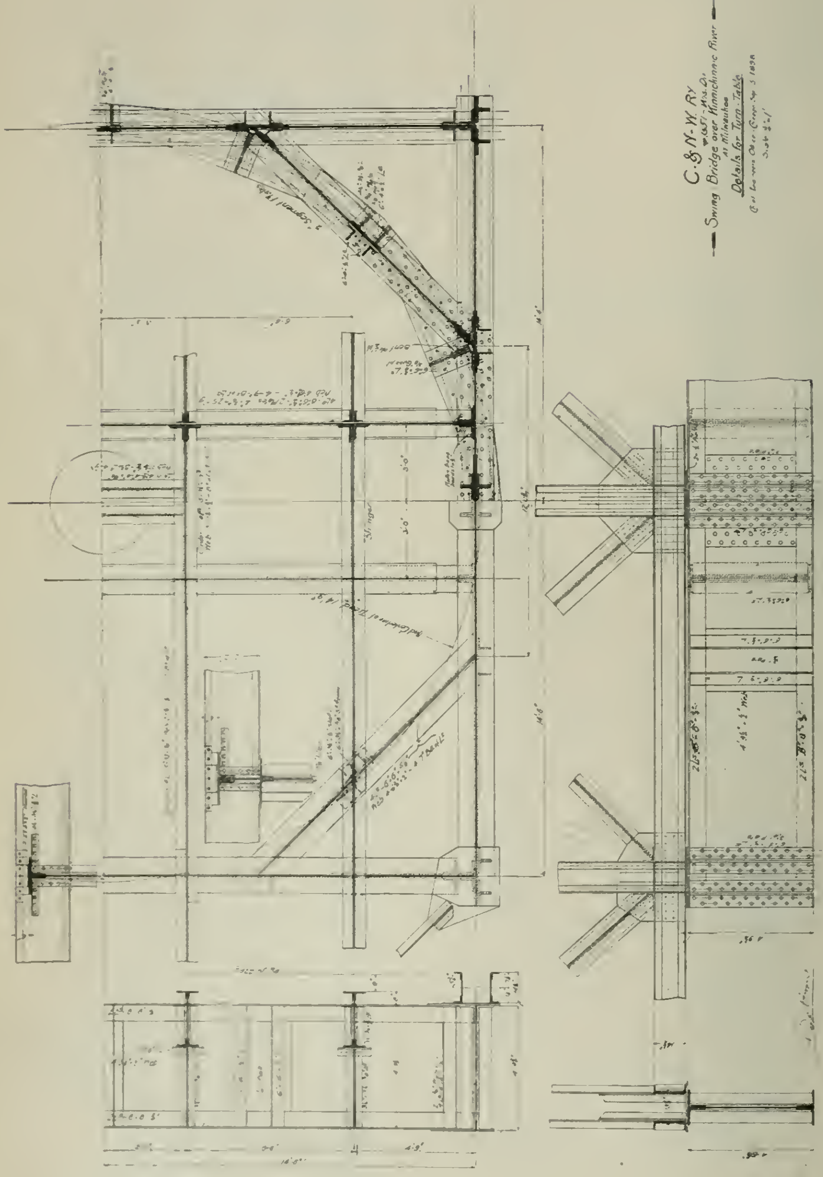

C. & N.-W. RY
Swing Bridge over Kinnickinnic River
at Milwaukee
Details for Turn-Table
Stringer

Fig. 6a.

given most excellent satisfaction, the bearing of the tread wheels being all that could be desired.

I am aware that a number of very large and heavy center-bearing swing bridges have been built in recent years, and are reported as giving very good satisfaction, yet I cannot think of any advantage they have over the combined center and rim bearing type, other than ease in turning, which I think is more than offset by the balance wheels that are required to steady the span while swinging.

Our eastern friends are building center-bearing bridges, and of course I know that they think that nothing good comes out of the west. But with the center bearing, nothing new has been used. As one of the earliest types, I believe the Port Adelaide swing bridge in Australia, designed by C. Shaler Smith, had a center bearing, and was built about twenty-six years ago. It consisted essentially of a center bearing—"Sellers center"—with balance wheels as used on the various types shown here tonight. Center-bearing swing bridges are nothing but locomotive turntables of larger growth.

From my experience I believe that the combined center and rim bearing will give better satisfaction than any other type.

Mr Albert Reichmann: The American Bridge Company has built quite a number of very large and heavy center-bearing swing bridges. Most of the troubles of center bearings are due to faulty design or materials. I think a center-bearing swing bridge up to at least 200 ft. is cheaper than any other arrangement, and gives as good service. There is no reason why they should get out of repair, and if repairs are necessary, the details should be so designed that these repairs can be readily made. It is purely a question of design. I think, however, I personally prefer a combined rim and center-bearing swing-span.

Mr. A. F. Robinson: In reference to the question of rim or center bearings on the swing bridges, of the Santa Fe System, the old Detroit Bridge Co. built a good many such bridges. One of the ideas in their design was to obtain a span that would swing as easily as possible, and one which would not shake or vibrate under traffic any more than is absolutely necessary. When they were left to their own judgment in the design, they usually adopted a combination between the rim and center bearing. In our own practice on the A. T. & S. F. Ry. system we use for short spans a plain center bearing. Where the span reaches a length of about 300 ft., whether for single or double track, we have used a combination of rim and center bearing so arranged that if it were necessary we could throw practically the entire load from the rim to the center, or vice versa, for a short time or during the passage of a few trains. I prefer a swing bridge with a good many bearing wheels. It swings more steadily, and even under traffic is more steady than the single pivot bearing. If I were designing for a pivot bearing entirely, I think I should put in almost as many balance wheels as though I were going to use a rim bearing.

When center wedges are used, they relieve the center pivot of all live load and shock so that the pivot does not have to stand anything but the static load of the bridge, and the girders each have a separate center support.

Mr. C. F. Loweth: The writer is of the opinion that it is impossible to make satisfactory swing bridges with either a center-bearing or rim-bearing turntable, and that the choice should depend on the conditions for each case, and this may not infrequently vary within quite wide limits. Many swing spans carrying heavy traffic are rarely opened, while others are frequently opened, and in still others the traffic over the bridge is light, and there are cases where very long swing spans are required by Federal authorities, but which are rarely, and some times never, opened; also, there are other bridges which are always closed for several months each year. This illustrates how the question of ease of operation of the bridge may or may not be a matter of prime importance. The writer believes that general consideration should first be paid to having a thoroughly rigid and otherwise satisfactory structure for the traffic passing over it.

The writer's preference and practice, stated in general, is for center bearings for short spans up to about two hundred ft. in length, and rim-bearing turntables for longer spans. He has no use for combined center and rim-bearing swing spans.

Long spans, for economy, must have a considerable height of truss at the center, and on this account it is necessary to have a correspondingly wide base, in order that the structure may have the desired stability under all conditions. A rim-bearing turntable probably meets this condition more easily and fully, all things considered, than is possible with a center-bearing table.

The writer does not agree with the view of some that a center-bearing table is preferable because it admits of a smaller center pier. This may be true for short spans and low piers, but there are certain proportions in the bottom dimensions of a center pier which are necessary for the desired stability of the structure as a whole, and these should be provided for, independently of the character of the turntable.

Mr. Andrews Allen: It seems to me that the question between center and rim bearings must be considered on the basis of first cost as well as maintenance. As to first cost, there is no question but that deck plate-girder center-bearing swing spans are much cheaper than rim bearing; also that they require smaller pivot piers and less height from base of rail to masonry. There is not so much difference in the cost of through plate-girder swing spans of rim or center-bearing construction, and the difference is still in favor of the center bearing. The pier, however, is only slightly smaller in the center bearing than in the rim bearing, but the difference in height is still very great. It must be borne in mind that the diameter of the center pier is a very important matter, as it usually fixes, to a large extent, the length of span on which depends the *clear opening* for navigation.

The difference in cost between center and rim bearings seems to decrease with the length of truss spans. I have made comparative figures between a 224 ft. single track through rim-bearing swing span and a 220 ft. center-bearing swing span designed for the same clear opening under "Frisco" specifications for "Cooper E-45" loading. The pound price figured exactly five cents in each instance, but the difference in weight was about 10 per cent in favor of the center bearing. The actual bidding prices were $22,850 for the center bearing, and $24,850 for the rim bearing, and which was actually built against our recommendation, however. The cuts show the stress sheets of these two designs. The rim bearing is of the simplest type, such as was frequently used by the late George S. Morison, and the drum is deep, with the trusses resting directly on it and giving a four point bearing. A combined center and rim-bearing turntable, would have been more expensive than either of the above. See Fig. 7 and Fig. 8.

The next illustration Fig. 9 shows the combined rim and center-bearing turntable of the 360 ft. single track through draw span for the Indiana, Illinois and Iowa Railway at Marquette, Illinois. This was a combined center and rim turntable on the old Detroit plan, giving an eight point bearing on the drum and distributing the load between the center and rim by means of levers.

The accompanying cut, Fig. 10, will show designs for center-bearing, plate girder swing spans. Use is made of a wedge or similar lift under the center of the girder. This center lift is driven to a firm bearing only, and generally has a spiral spring inside of the wedge to insure its bearing, in case the end wedges bear differently. We always use from six to eight balance wheels and find no difficulty in maintaining the stability of the span. There is, however, considerable vertical movement of the ends while the span is turning, this being due to the clearance between the balance wheels and the track. The writer has observed about ½-in. vertical teetering on a 210 ft. through center-bearing swing span. This teetering does no harm, but must be provided for in designing the end lift.

The center-bearing swing span, when wedges are driven at the center is certainly as satisfactory as a rim-bearing span under passage of trains; it turns more easily than the rim-bearing design, and, up to moderate lengths at least, is sufficiently stable while turning. It has less parts and those parts are simpler than the corresponding parts of a rim-bearing span. The writer's preference is, therefore, for the center-bearing span up to lengths as will show sufficient stability while turning, and a lower first cost, and he would not hesitate to use the center-bearing type for single track spans, up to 300 ft.

Mr. C. C. Schneider: The writer takes exception to some of the

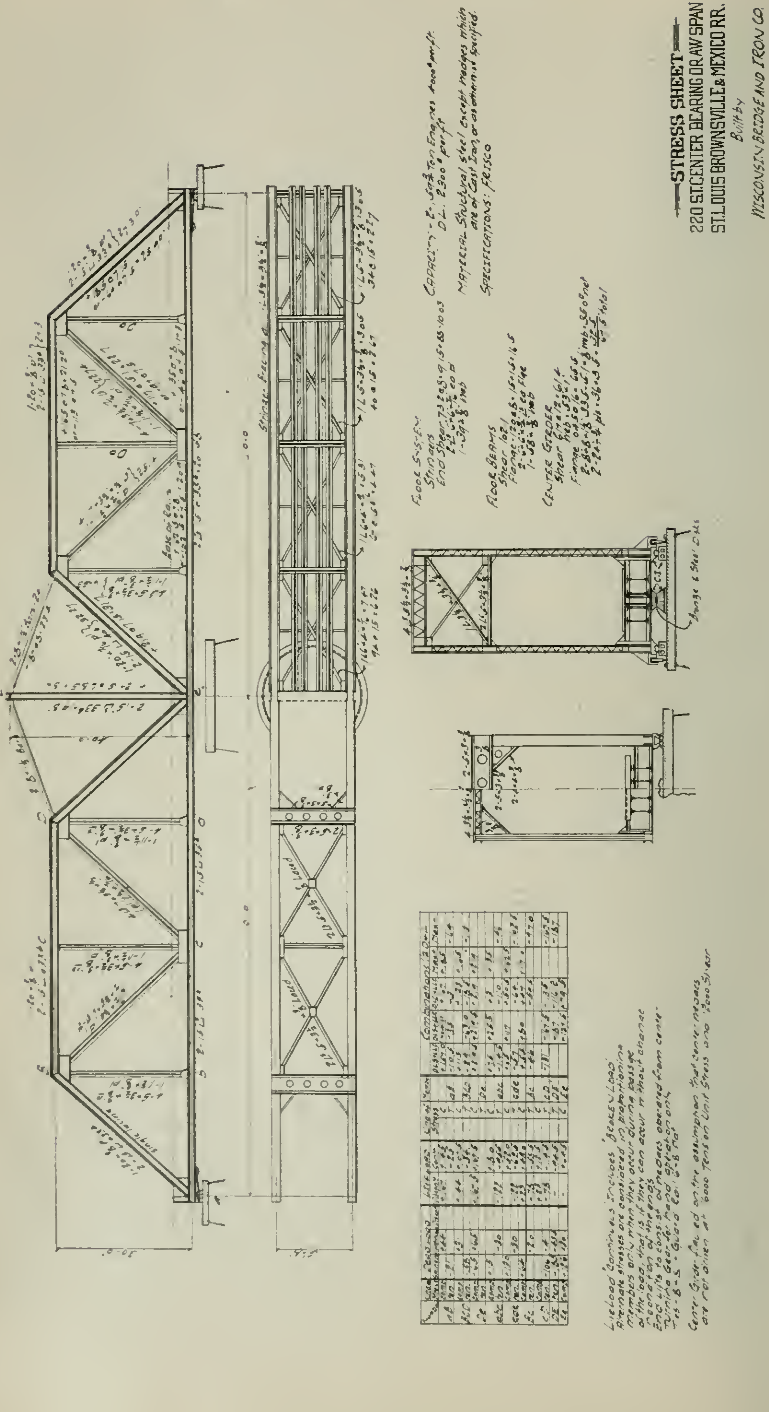

STRESS SHEET
220 ST. CENTER BEARING DRAW SPAN
ST. LOUIS BROWNSVILLE & MEXICO RR.
Built by
WISCONSIN BRIDGE AND IRON CO.
CAPACITY - E. 50 Ton Engines 4000# per ft. D.L. 2300# per ft.
MATERIAL Structural steel except wedges which are of Cast Iron or as otherwise specified.
SPECIFICATIONS: FRISCO
FLOOR SYSTEM
Stringers
FLOOR BEAMS
CENTER GIRDER
Compressions
Live Load includes Broken Load

Fig. 7.

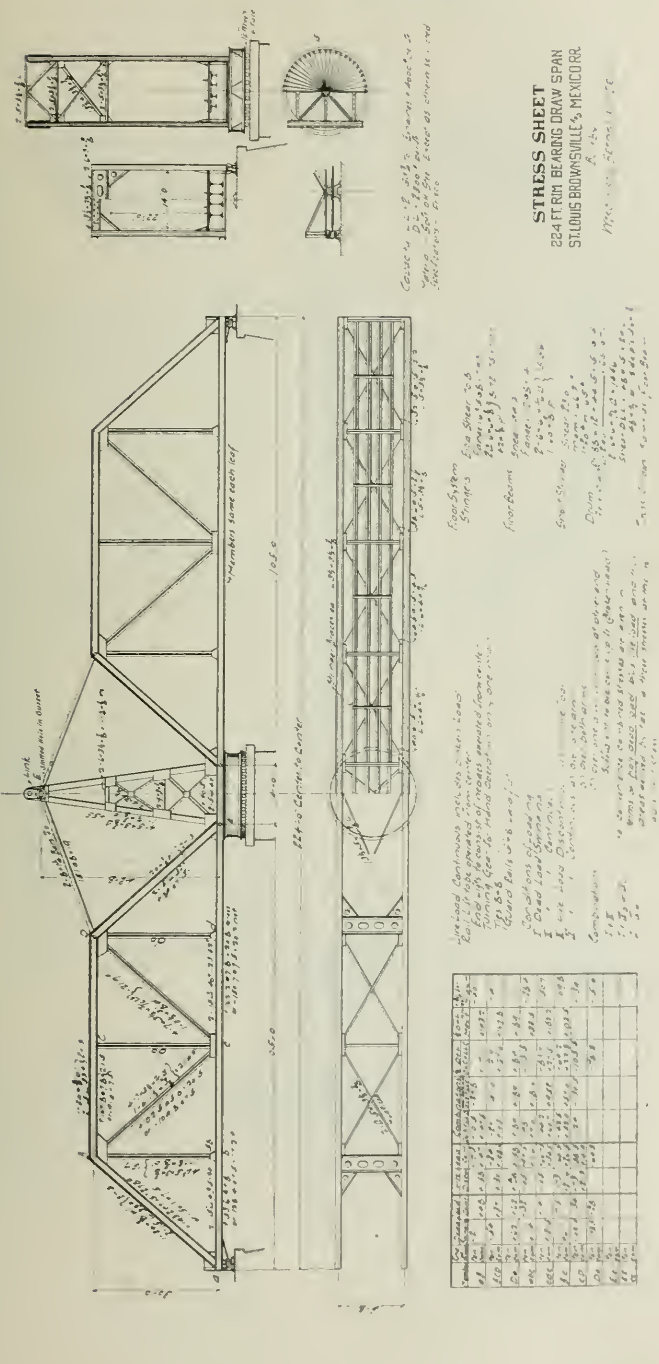

STRESS SHEET
224 FT. RIM BEARING DRAW SPAN
ST. LOUIS BROWNSVILLE & MEXICO RR
Members same each leaf
105-0
224-0 Center to Center
Link
Floor System
Stringers
Floor Beams
Drum

Fig. 8.

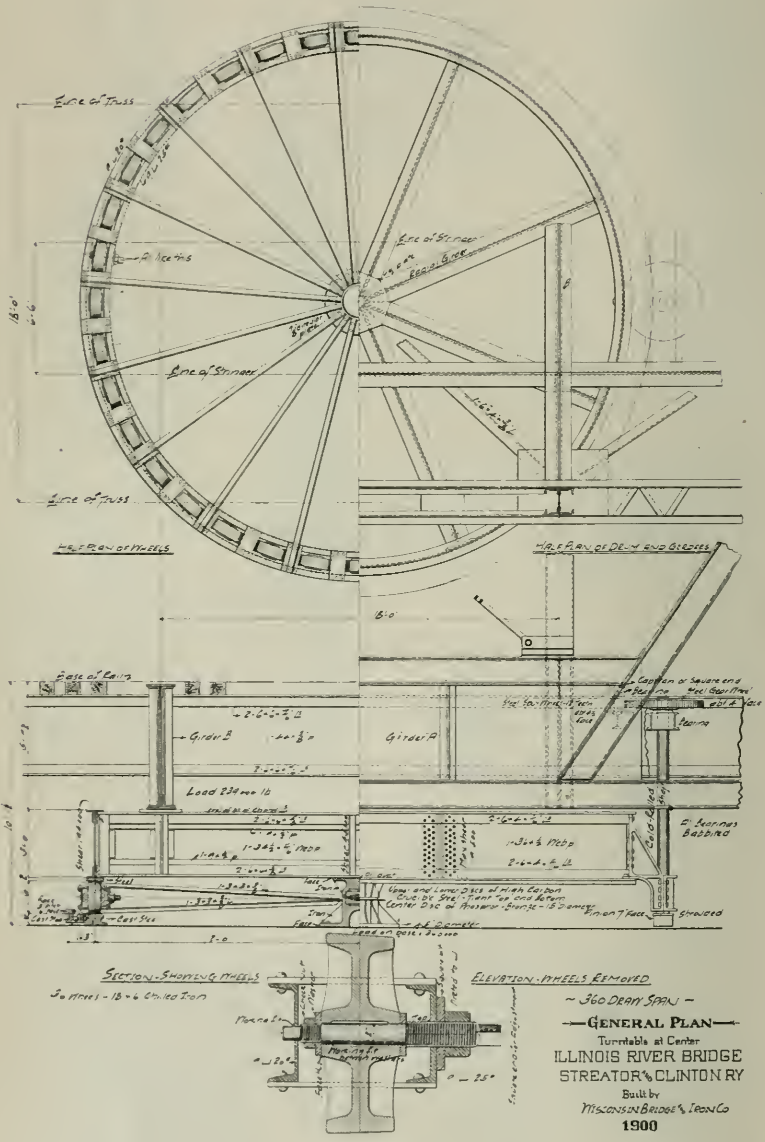

Line of Truss
Line of Stringer
Radial Girder
B
18'-0"
6'-6"
Line of Stringer
Line of Truss
HALF PLAN OF WHEELS
HALF PLAN OF DRUM AND GIRDERS
16'-0"
Base of Rails
Girder B
Girder A
Load 234 000 lb
1-36 × ½ Web p
2-6 × 4 × ⅝ L
Capstan or Square end
Bearing
Steel Gear Frame
Bearing
Face
Cold-Rolled Shaft
Bearings Babbited
Pinion 7" Face
Shrouded
Upper and Lower Discs of High Carbon Crucible Steel - Tempered Top and Bottom. Center Disc of Phosphor-Bronze - 15" Diameter
Steel
Cast Steel
Lead on Base
SECTION - SHOWING WHEELS
ELEVATION - WHEELS REMOVED
~ 360 DRAW SPAN ~
GENERAL PLAN
Turntable at Center
ILLINOIS RIVER BRIDGE
STREATOR & CLINTON RY
Built by
WISCONSIN BRIDGE & IRON CO
1900

Fig. 9.

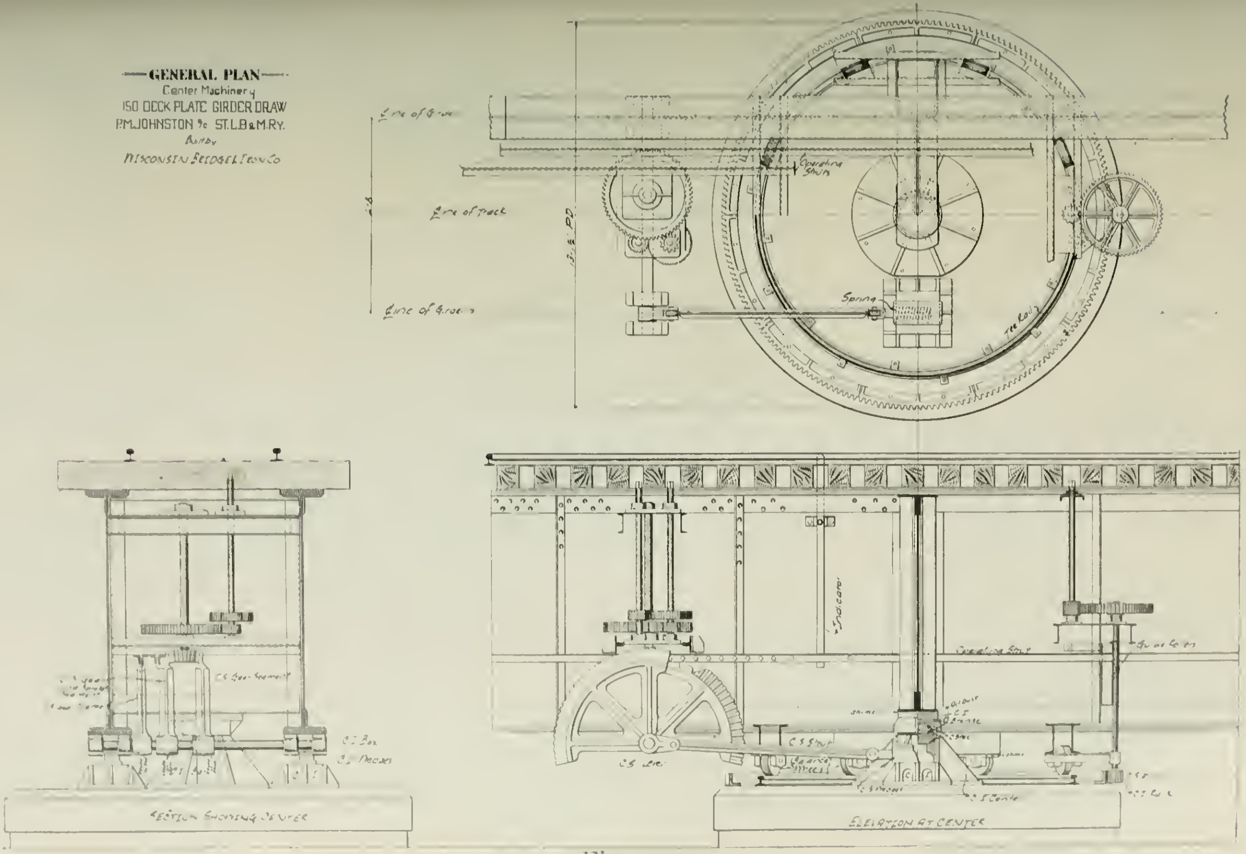
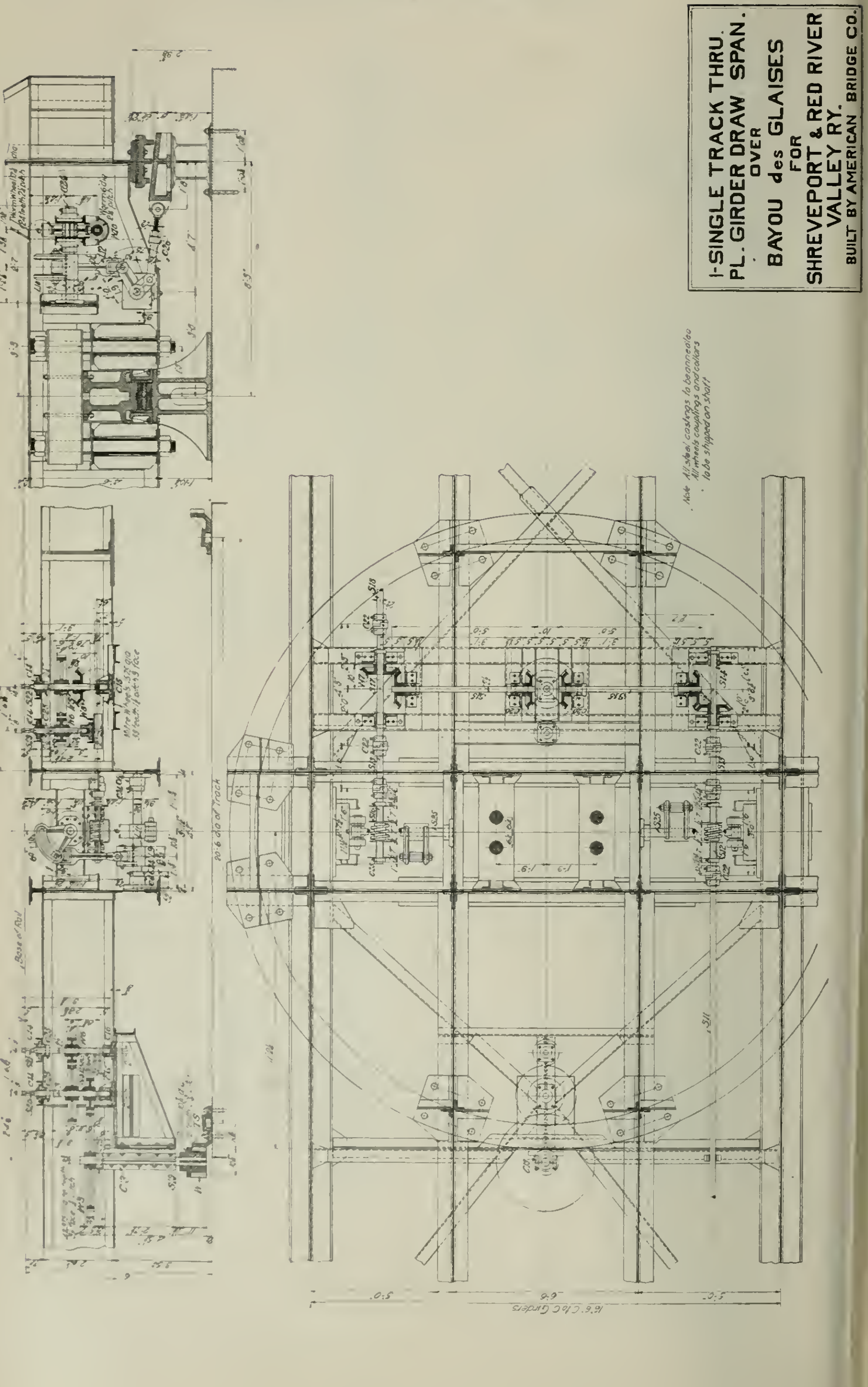

GENERAL PLAN
Center Machinery
150 DECK PLATE GIRDER DRAW
P.M.JOHNSTON Gc ST.L.B.&M.RY.
Aunby
WISCONSIN BRIDGE & IRON CO
Line of Girder
Line of Track
Line of Girder
Operating Shafts
Spring
Tee Rail
Indicator
Operating Shaft
C.S. Strut
C.S. Lever
Wheels
C.S. Centre
C.S. Box
C.S. Gear Segment
SECTION SHOWING CENTER
ELEVATION AT CENTER

Fig. 10.


1-SINGLE TRACK THRU.
PL. GIRDER DRAW SPAN.
OVER
BAYOU des GLAISES
FOR
SHREVEPORT & RED RIVER
VALLEY RY.
BUILT BY AMERICAN BRIDGE CO.
Note: All steel castings to be annealed. All wheels, couplings and collars to be shipped on shaft.
20'-6" dia. of Track
16'-6" C. to C. Girders
Base of Rail

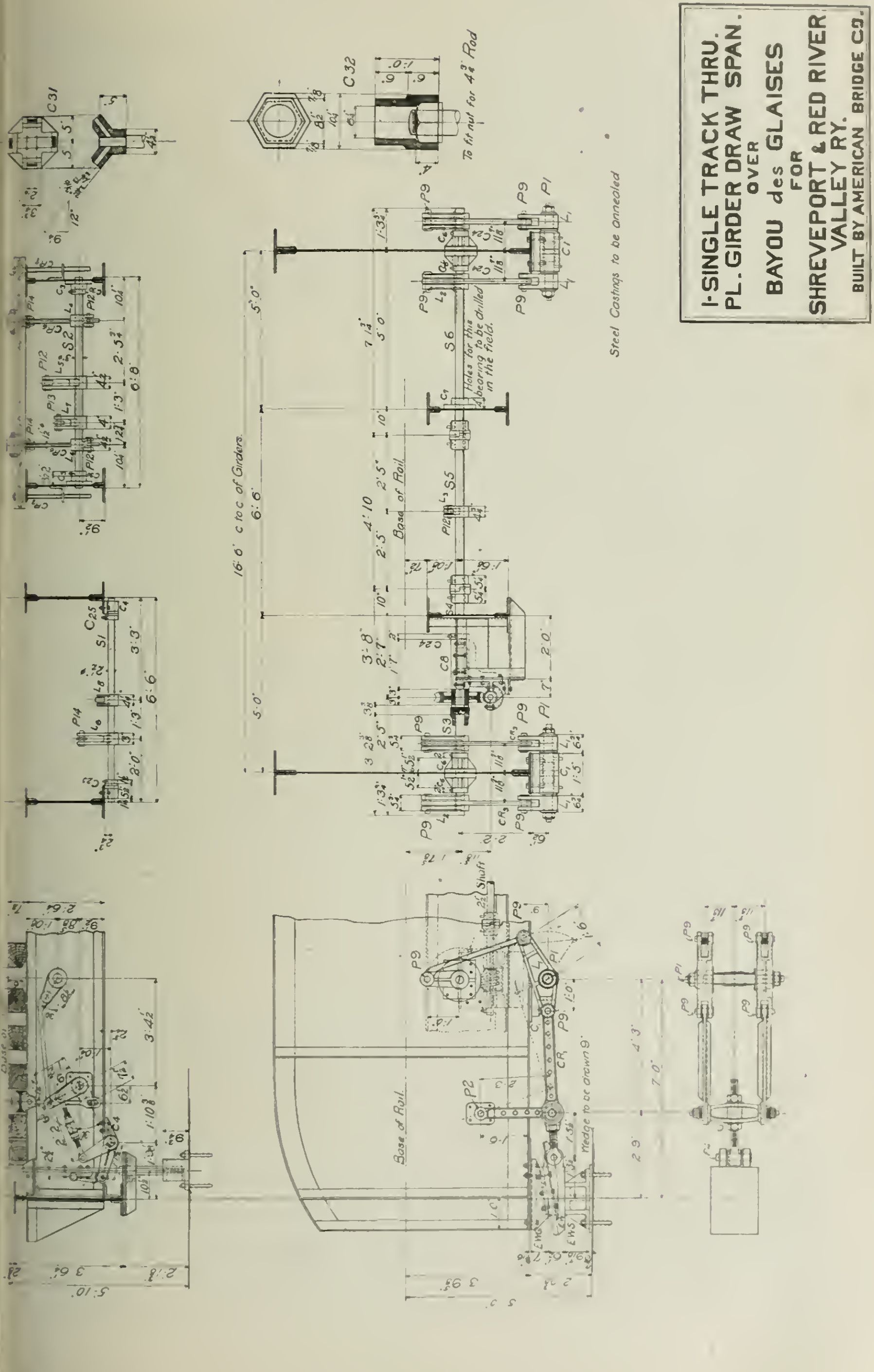

I-SINGLE TRACK THRU.
PL. GIRDER DRAW SPAN.
OVER
BAYOU des GLAISES
FOR
SHREVEPORT & RED RIVER
VALLEY RY.
BUILT BY AMERICAN BRIDGE Co.
C31
C32
To fit nut for 4¾" Rod
Steel Castings to be annealed
16'6" c to c of Girders
Base of Rail
Holes for this bearing to be drilled in the field.
S1
S2
S3
S5
S6
C8
C24
C25
P1
P2
P9
P12
P13
P14
CR
Wedge to be drawn 9"
Shaft

Fig. 12.

statements made by the author in reference to center-bearing turntables, as they do not agree with his own experience with the modern type designed in accordance with good practice. The pivot, for instance, shown in Fig. 2, used on a bridge over St. Croix river, is not designed in accordance with the writer's ideas of good practice. The connections between the pivot and trusses should be adjustable as to height, and should be so designed that the discs can be taken out and examined, and new ones inserted if necessary while the bridge is not in operation and without interfering with the traffic over the bridge. This can be accomplished by an arrangement similar to that shown by Figs. 11 and 12, showing details of bridge over Bayou des Glaises built for the S. & R. Riv. Val. R. R.

The experience of the railroads who have had properly constructed center bearing turntables in operation for the last fifteen years or more, such as the Pennsylvania R. R. and many others, is that the center-bearing turntables of the modern kind have given less trouble and are cheaper to maintain than the best types of rim-bearing turntables. In fact the center-bearing turntable has proved so satisfactory that practically all railroads who have used them once have used them ever since, and wherever a swing bridge with a rim-bearing turntable had to be renewed, it was replaced by one of the center-bearing type.

A swing bridge is composed of two parts; the static structure, carrying the traffic, and the machinery. While the bridge is closed and carries the traffic of the railroad it should be as near as possible a static permanent structure. This condition can only be realized if the bridge rests on solid, substantial supports, but not if it is supported on wheels. For good substantial supports nothing is equal to wedges as they are the nearest approach to bolsters or bed plates of fixed spans.

The principal advantages of the center-bearing over the rim-bearing turntable are:

First: Economy in first cost.
Second: Economy of maintenance.
Third: Greater stability.

Economy in first cost: The most costly piece of structural work in a rim-bearing turntable is the drum. In a center-bearing turntable a pair of plain riveted girders are used in its place. There is no ambiguity of strains in these girders and the cost of shop work is equal to that of ordinary plate girder work. In place of the great number of heavy rollers and heavy track segment in the rim-bearing table which must be accurately finished, eight light trailing wheels with one comparatively light lower track are used in the center-bearing turntable. The trailing wheels and track carry no load except wind and are used only to balance the bridge while swinging. The only part of a center-bearing turntable which is more expensive than the corresponding part of a rim-bearing turntable is the pivot. The operating machinery required in both cases is practically the same, although it takes considerable less power to turn a bridge with center bearing than one with rim bearing.

Economy of maintenance: The structural part of the bridge with center bearing, being apart and distinct from the moving portions of the bridge, requires no more care than any other permanent structures designed in accordance with good practice. The moving parts and the machinery of a swing bridge are the pieces that wear out and have to be repaired or renewed once in a while. In a center-bearing turntable the discs of the pivot are about the only pieces besides the machinery that wear out and have to be renewed.

Another advantage in the maintenance of the center-bearing over the rim-bearing turntable is, that the former is not materially affected by any settlement of the masonry, as the height of the bridge can be adjusted, as well as the trailing wheels and the wedges supporting the bridge.

The reason why the swing bridge with center-bearing turntable has more stability has already been explained. Another advantage the center-bearing turntable has over the rim-bearing turntable is that it requires less height from top of masonry, to base of rail, which in some cases is of the utmost importance in keeping the track above water.

In my opinion the center-bearing type of turntable should preferably be used wherever practicable, and can be recommended for single track bridges up to 500 ft. and for double track bridges up to 400 ft. span.

Center-bearing turntables should be designed so that the entire dead load of the bridge is carried on a center pivot when the bridge is swinging, but when the bridge is closed the trusses should rest at the center on wedges or other substantial supports. These supports must be strong enough to resist the reaction resulting from the live load and impact of the train. Trailing wheels running on a circular rack should be provided for the purpose of balancing the bridge and to carry the wind strains to the track while swinging. The center pivot as well as the trailing wheels should be adjustable as to height. The center pivot should be so designed that the discs can be taken out, examined and replaced, when the bridge is not in operation without interfering with the railroad traffic.

Mr. F. C. Kunz, (read by R. E. Belknap): The author's arrangement of the center deep in the masonry (Fig. 2), is very commendable, as it will "fix" the center of the turntable; but, if it is advisable to have a fixed center, as in Fig. 1, up to 300 ft. spans, and a fixed center carrying half of the dead load, as in Fig. 2, for spans over 300 feet, why not carry all the dead load in the centre, making the centre "fixed," without the disadvantage of interference with the construction of the masonry, as in Figs. 1 and 2.

In rim-bearing swing spans, the drum is seldom sufficiently deep to distribute uniformly among the rollers the whole weight of the span, which will cause an uneven wearing of the rollers, especially if combined with a settlement of the pivot pier. This uneven wearing, once started, will progress so fast that it is only a question of time when it will cause serious trouble. It seems to us that the same objection which the author expresses against the use of a center bearing with conical rollers, as uneven wearing, sliding, costly taking out, etc., applies, to a great extent also, to a rim-bearing turntable. Our experience with rim-bearing swing bridges which have been in service a few years has convinced us that there are always some rollers which do not get their share of the load, some even not bearing at all, whatever the cause in each particular case may be.

The objection the author has against the usual center bearing is the wearing of the discs: that seems to us rather a question of material and allowable working pressure than of the disadvantage of center bearing. The author, himself, in Fig. 2, uses a phosphor-bronze disc between steel discs, and it would be interesting to know how much working pressure he allows per square inch. Several years ago, when phosphor bronze was a very poor material, "flowing" under a pressure of less than 6,000 lbs. per sq. in., some railroad companies used steel also for the center disc of center-bearing swing bridges and turntables, which, however, increased the friction and caused cutting. The phosphor bronze of today has an elastic limit of not less than 20,000 lbs. per sq. in., and the working pressure usually allowed is about 3,000 lbs. per sq. in. of disc when the bridge is swinging. For smaller discs, where the lubrication is comparatively more profuse than in the case of larger discs, a higher figure can safely be used, as is done in locomotive turntables with disc bearing. The noise which is sometimes noticeable when turning new center-bearing swing bridges usually ceases after everything has a proper bearing and is of no further consequence. And should a replacing of the disc be desirable, after a service of say, twenty years, it certainly is an easy operation, if the center is properly designed, and this can be done without interrupting the traffic over the bridge, while, on the other hand, the replacing of a roller in a rim bearing will undoubtedly be more troublesome. The author states that he found some balance wheels over-loaded and cutting the circular track. This does not need to happen if the wheels are adjustable.

The Pennsylvania Steel Company have at present in their shops at Steelton the following swing bridges in process of manufacture:

1 Bridge, Single Track, Plate Girders, 136 ft. long, with center bearing.

2 Bridges, Double Track, Plate Girders, 74 ft. long, (Uneven Arms) with center bearing.

1 Bridge, Double Track, Plate Girders, 106 ft. long, with center bearing.

1 Bridge, Single Track, Riveted Trusses, 257 ft. long, Combination of center and rim bearing.

1 Bridge, Single Track, Riveted Trusses, 314 ft. long, Combination of center and rim bearing.

1 Bridge, Single Track, Plate Girders, 87 ft. long, (Uneven Arms) with center bearing.

2 Bridges, Single Track, Riveted Trusses, 250 ft. long, with center bearing.

1 Bridge, Single Track, Riveted Trusses, 200 ft. long, with center bearing.

1 Bridge, Double Track, Riveted Trusses, 327 ft. long, with center bearing.

The last named bridge is for a large eastern railroad with very heavy traffic, and will be the heaviest drawbridge with center bearing in existence. This bridge will have a phosphor-bronze disc of 33 in. diameter between hardened steel discs. From this table it would seem that the popularity of center-bearing swing bridges is rather increasing.

Properly designed center-bearing swing bridges with wedges at the pivot pier to take the live load reaction when the bridge is closed, with a sufficient number of adjustable balance wheels and with wedge lifts, have given, in our experience, perfectly satisfactory service, probably just on account of their simplicity, which the author rightly calls one of "the prime requisites to economical operation and maintenance."

Mr. C. L. Strobel: The writer would endorse the author's conclusion that center-bearing turntables for swing bridges do not offer practical advantages over rim bearing, and they are also more expensive for the longer spans.

Mr. J. W. Schaub: The strictures placed by the author on center-bearing swing spans is hardly in keeping with the present practice, and it is not in accord with the results obtained in operating such spans for a number of years.

Center-bearing swing spans are not only cheaper to build, but are also cheaper to maintain and easier to operate. Moreover, owing to the small depth required, between the base of rail and top of pier, this form of bridge lends itself more readily where this distance is limited, and where it is desirable to keep the top of the center pier well above extreme high water. It is only in such cases as for double track spans, or such spans where the width of roadway is very large, that the center-bearing type of bridge becomes impracticable owing to the great depth required for the cross girders directly over the pivot. However, this does not appear until the spans for double track exceed say 400 feet, and for single track bridges it is doubtful if this limit is reached under 550 feet. Heretofore, the difficulty in providing an adjustment for the center pivot, which would be practicable for very long spans, is now overcome by simply throwing the adjustment into the side bearings, which heretofore have been made immovable. Also, by making the side bearings adjustable the wedges are entirely eliminated, thereby simplifying the operating mechanism. In this case, four side bearings are used, instead of two, placed equidistant and forming a square upon the four corners of which the bridge finds a reaction for the moving load only. At the same time these supports serve to steady the bridge when it is standing open. Moreover, the center pier can now be made square instead of round, using less yardage than heretofore and costing less per yard. In addition to this, where a protection is provided for, up and down stream, the square pier offers many advantages. The writer has designed and built a number of plate-girder swing spans on this plan, up to 150 feet long, and he sees no reason why this plan is not applicable in any case, inasmuch as the center cross-girder now consists of two separate cross girders, making it applicable to spans of any length, where heretofore the single cross girder became impracticable for very long spans.

NO. 2: DETAILS OF TURNTABLE AND CENTER PIVOT:

Mr. W. H. Finley: The results of the experiments made by the late Col. C. Shaler Smith in 1874, published in Vol. III "Transactions of the American Society of Civil Engineers," under the title of "Draw Spans and their Turntables," served for years as a general guide for the design of swing bridges. The later experiments made by Alfred P. Boller, J. W. and H. J. Schumacher, on the Thames River Bridge, Connecticut, and published in Vol. XXV Transactions of the above Society, gave us some valuable information regarding rolling friction and the power necessary to operate swing bridges.

With reference to the live ring, one would infer from Mr. Cartlidge's paper that it was no longer accepted practice to use radial rods to connect the wheels of the live ring to the spider at the center casting.

The writer has had considerable experience with a large number of draw bridges of different types, where the details of rim wheel fastening varied considerably, and has had trouble with only one bridge, and this was a case where the rollers of the live ring were not spaced but left free to move, being held only by the radial rods. The writer has had no trouble with a system of radial rods properly spaced on the inside and outside, and is of the opinion that with reasonably good workmanship, and the use of tangental rods to insure the relative movement of the spider and ring, this method will give entire satisfaction.

Referring to Fig. 13—details of the Winona bridge—the writer would call special attention to the design of the wheels, treads and rack. You will note that the treads are of cast iron with steel plates for wearing surfaces, the joints of the steel plates being mitred and break joints with the cast iron treads. The writer also

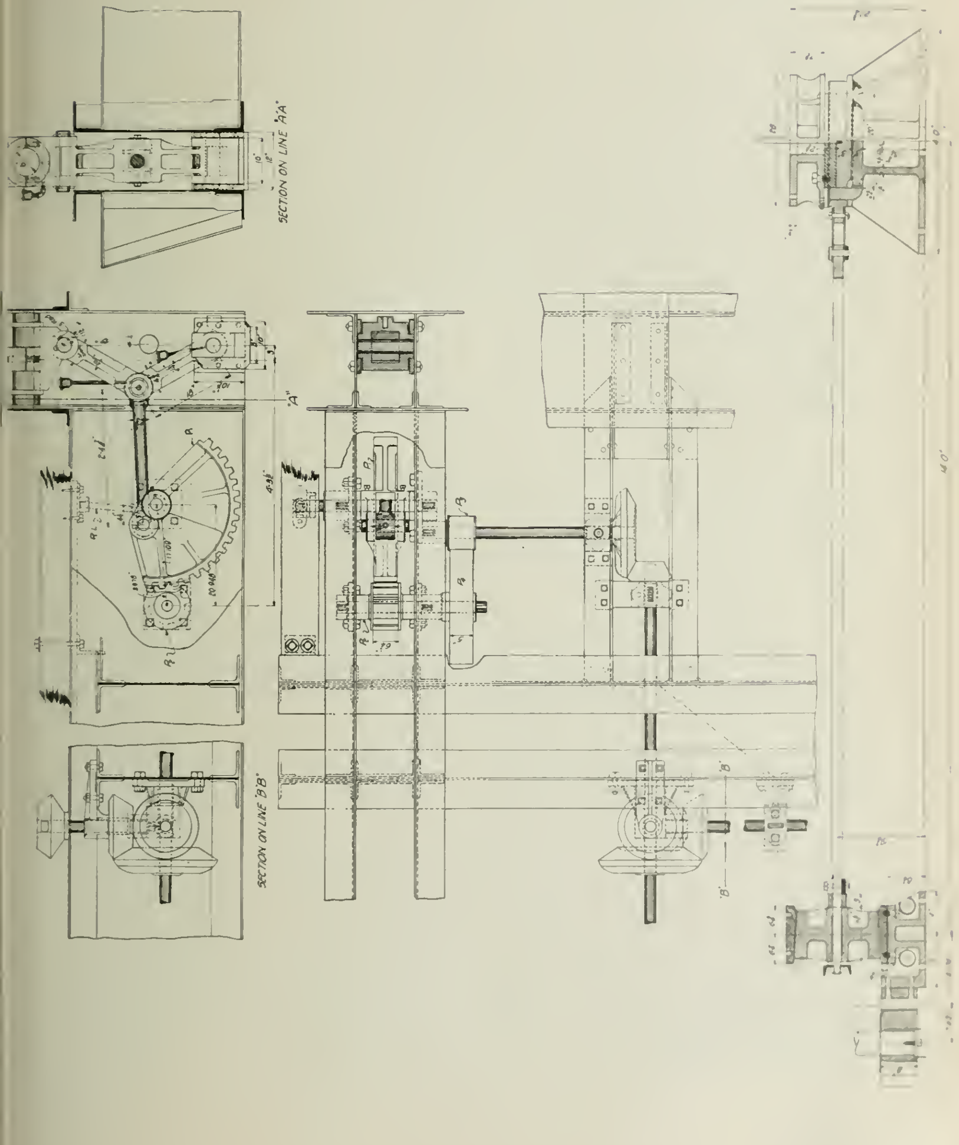


Fig. 13.

believes that the method here shown of fastening the rack to the tread is much superior to attaching it by anchor bolts through the flange of the treads into the masonry, as shown in Mr. Cartlidge's plans, in which design the whole stress from turning is thrown onto the anchor bolts, instead of being carried to solid parts that carry load. The writer fastens the rack to the vertical face of lugs projecting from the bottom tread, and arranges these lugs so that they can be finished to a plane surface.

Considering the draw bridge question from maintenance standpoint, there are a great many points, not usually considered, that must be given careful attention for economy of first cost and of maintenance afterwards. *The design should be such that repairs can be made without serious interruption to traffic.* The connection of the rack to the tread should be such that a segment of rack may be taken out without having to jack up the bridge or take out other parts, and the rim wheels must be similarly arranged, so that any wheel may be removed with the minimum of difficulty. The writer does not know whether, with the stiff frame around the rim wheels (as shown by Mr. Cartlidge) instead of radial rods, it would be easier to remove one of the wheels or not, but he has had occasion to remove a great many wheels, and always appreciates a design that permits their ready removal. It is also better to design the spider in two parts, so that if it is necessary to replace it, you can do so without packing up the girders or removing the whole center. The pivot itself should be designed so that it can be taken apart without jacking up the arms to take the pivot bearing out.

The author seems to lay considerable sturess on imbedding the center casting in the masonry, but the writer has never found that this particular point was of very great moment as compared with other details.

The writer has learned from experience working nights and Sundays over draw bridges, how important it is to have the details so designed that repairs or replacements can be made rapidly, cheaply and without dismantling the bridge.

In regard to the design of the pivot center, Fig. 13, illustrates the type of center pivot used on the bridge over the Kinnickinnic River, built about eight years ago. The center consists of a phosphor bronze disc bearing on a forged steel disc, the bearing surfaces being twenty inches in diameter. We has some trouble with this center at first, owing to the fact that the shop made the phosphor bronze plate slightly concave instead of convex as they had been instructed to do. This threw the pressure out, increasing the radius of friction materially and resulting in hard turning; in fact the phosphor bronze ground into the steel plates. When it was taken apart, we found the steel covered with phosphor bronze. The disc was trued up to a slightly convex surface and afterwards gave no trouble.

While the writer has used the flat disc center (as shown in Fig.

13) in a number of other cases, and has had no trouble, he is of the opinion that it is not as efficient as the lenticular disc center, shown in Fig. 2 of Mr. Cartlidge's paper.

The writer is, however, surprised at Mr. Cartlidge's experience with conical rollers. This type of bearing has been used for a great many years, and when properly designed and made of the proper materials, has given satisfaction. Some of our earliest swing bridge centers were made with conical rollers, evidently, a development of the conical roller center-bearing of a locomotive turntable.

In Fig. 14 is shown a conical roller center that will be recognized at once as what has been known for years as the "Sellers center." Usually this center consists of only one ring of conical rollers. The center here shown has two concentric rings of rollers, and was put into service about twenty-two years ago on the double track swing bridge carrying the tracks of the C., M. & St. P. Ry. over the north branch of the Chicago river at Kinzie street. The center was in use under this bridge for about eight years and sustained a pressure when in motion of about 600,000 lbs. or 4,000 lbs. per lineal inch of roller of 4-inch and 3-inch large diameters. This same design of center, Fig. 14, taken from the C., M. & St. P. bridge, has been in use under the Kinzie street swing span of the C. & N. W. Ry. for the past nine years, and is still giving excellent service.

The writer will also mention a conical center in use under a turntable in this city, turning on an average over 400 times in each twenty-four hours, and which is giving perfect satisfaction, having turned 292,000 times in the two years during which it has been in operation.

These two instances and a number of others that the writer calls to mind have convinced him that a conical roller center of proper material, design and workmanship is very satisfactory.

Troubles may come, to a slight degree, from poor material and workmanship, but they come principally from faulty design. In the old "Sellers center" the length of the roller was generally the same as the large diameter, and in rollers of this proportion it is not necessary to use a spider or cage to maintain the radial position of the rollers. When, however, the length of the roller materially exceeds its large diameter, it becomes necessary to use a spider or cage to hold the rollers in line, and this fact has been too frequently overlooked in designing such centers.

The writer also wishes to call attention to the necessity of keeping all working parts properly and regularly oiled, and of providing suitable methods for convenient and efficient cleaning and oiling.

Mr. C. L. Strobel: The writer wishes to commend papers of this kind. A swing bridge is a machine and like most machines can be improved by a study of its actual performances. A paper giving the results of observation and of a critical study of various designs, such as this, is valuable, and we should have more of them.

The writer does not share the author's objections to cone-roller centers. Such roller bearings can and have been built of such efficiency that they do not require repairs, but in order that there may be no uncertainty as to results, he thinks it essential that a spider be used to hold the rollers positively in their relative position, which arrangement has the further advantage of reducing the friction to a minimum. He agrees with the author that for swing bridges, ordinarily, the reduction in friction from the use of cone rollers does not sufficiently pay for their greater cost.

The writer has for a long time followed the practice of connecting the outer ring (usually made up of channels) which holds the wheels in their relative position, to the plate or inner ring which holds the inner ends of the radial bars, by means of a system of triangulation such that the outer ring cannot move without taking the inner ring along with it. If his arrangement is not used, the stiffness of the radial bars must be depended upon to accomplish the same object, and there may then be an undesirable tendency for the wheels to "skew," and the inner ring to lag behind the outer ring, in its motion.

Imbedding the center and the track castings in concrete, does not appear to the writer as essential to good results, but, if practiced, it would appear desirable to raise the track surface above the concrete instead of leaving it flush with it. By so doing the track would be kept freer from dirt.

Mr. C. C. Schneider: The designs of rim-bearing turntables accompanying the author's paper are in accordance with good practice, and will obviate some of the trouble experienced in operating and maintaining swing bridges with rim-bearing turntables. The features which are particularly to be recommended in these designs are not new but are not always adopted by designers. They are:

1st. Setting the pivot casting into the concrete of the pier. Much trouble has been experienced in the past from the loosening of the pivot. This has been one of the principal objections to the rim-bearing turntable in former years, when concrete was not so extensively used as at present, and when it was the usual practice to set the pivot on a stone pedestal to which it was fastened with stone bolts.

2d. Adopting the modern practice of using stiff rings with stiff radial struts instead of the antiquated live ring with adjustable radial rods, found in most of the other turntables. The writer also wishes to confirm the author's statement that centers with conical rollers have proved a failure in every case where he has used the same, and in every other case which has come to his knowledge. The writer has been designing, inspecting and repairing all kinds of movable bridges since 1875, and is therefore in a position to say a few words about the early history and development of the swing bridge.

Center-bearing turntables of swing bridges up to 1880 consisted of a center pivot and balance wheels; these wheels answered the double purpose of balancing the bridge while swinging, and of supporting their portion of the live load when the bridge was closed. This kind of construction was generally used for single track bridges only. Some of these bridges proved satisfactory but others did not. Those that gave the most trouble had pivots with conical rollers.

Some center-bearing turntables with disc pivots also proved unsatisfactory on account of poor material and workmanship, and bad design. In some cases the discs were made of ordinary steel without being hardened or not properly polished, or had no effective arrangement for lubrication and for keeping out the dust.

The combined rim and center-bearing turntables built in those days were also unsatisfactory on account of the uncertainty of the distribution of the load between the drum and center pivot.

In the combination turntable of the usual construction the adjustment depended entirely on the judgment of the erector, and it frequently happened that either the drum or the center had to carry the whole load for which neither were designed, and repairs on these turntables were particularly troublesome.

In 1880 the writer had occasion to design a double-track swing bridge over the "Dutch Kills" on the Long Island railroad. The Dutch Kills at that time was not navigable, but the law required a swing bridge. It occurred to the writer that a bridge which is to be used as a fixed span, but must be designed so that it can be opened, should meet, in the first place, the conditions most desirable in a permanent structure, viz., when closed it should be practically a fixed span, resting on substantial supports, which, however, could be removed if it should become necessary to open the bridge. This, to the writer's knowledge, was the first swing bridge where wedges were used as supports at the center. The arrangements for operating the wedges was very crude, and when the channel was made navigable in 1893, this bridge was replaced by a three-track structure with a center-bearing turntable of a more improved design, meeting the requirements of navigation and the increased traffic of the railroad.

In 1881 the writer designed the single track 346-ft. swing span of the Snake river bridge on the Northern Pacific R. R. The bridge was to be opened only at long intervals, and as the trains were few, the time required for opening and closing was considered of no importance. It was rather desirable to have the bridge as near a fixed span as possible when closed. For this reason wedge supports were used at the center and ends, and the operating machinery was designed as simple as possible and for hand power only.

In the same year the writer designed another single track swing bridge of 228-ft. span on the same principle as the Snake river bridge. A plan and description of the center and end lift of this bridge was published in the *American Engineer* of August 11, 1882. The details are described as follows:

> "The novel feature of this turn-table is the central support of the trusses on the pivot pier when the draw is closed. It will be seen, by reference to the plans, that when the draw is closed the trusses transmit their load through movable cast iron wedges directly to the pedestals on the piers at the center, as well as at the ends, giving the bridge a firm support and actually making it a continuous fixed span over two openings. When the bridge is to be swung, all the supporting wedges are drawn by means of a screw transmitting its motion through knuckle joints to the wedges, shown on the plans, thus leaving the bridge free to swing on the center pivot. The trailing wheels carry no weight; they are adjusted to have a little clearance and are only for the purpose of steadying the bridge while turning. The trusses at the center rest on bolsters, which are supported by two cross girders, and these are connected near the center by two box girders. After the supporting wedges are removed, the whole structure is suspended from the pivot by six 3 in. bolts, passing between the double web of the box girders and 15-in. I-beams which rest on the center directly over the pivot. This pivot is made of steel and case hardened."

These first designs of center-bearing swing bridges with wedge supports, prepared by the writer, were for bridges which were to be opened at long intervals only; for swing bridges which had to be opened frequently, he used the rim-bearing type. At the same time he improved his center-bearing type with a view of adapting it particularly to bridges requiring quick operation, for which purpose it appeared this type was especially fitted, offering the advantages of less power and less wear and tear than the rim-bearing type.

Since 1886, when the writer became connected with the Pencoyd Iron Works, he was ably assisted by his brother, E. A. Schneider, engineer in charge of the drawing room, in making additional improvements in the pivot and details of the operating machinery until the present modern type was evolved, generally known as the "Pencoyd type of swing bridge" as illustrated in Figs. 11 and 12.

There have been built seventy-five center-bearing swing bridges in accordance with the writer's type of construction by the Pencoyd Iron Works, and later by the American Bridge Company, alone, and many more by other bridge companies who adopted his design. Whenever a railroad has used the modern center-bearing swing bridge once, it has been used again and again to the present day. The Pennsylvania R. R. has built nineteen bridges of this type since 1890.

Mr. F. H. Bainbridge: The efficiency, ease of operation, and good condition of swing spans, when operated frequently, will depend largely on the care with which all parts are kept in adjustment and on the manner in which they are cleaned and oiled. In some northern cities navigation is kept up during temperatures of from 20 to 30 degrees below zero. Very few oils retain their efficiency at these temperatures. The best oils for heavy pressure, such as center bearings under such conditions, are the light gravity mineral oils, such as are used for lubricating refrigerating machinery. The oil should be perfectly fluid at low temperatures and should spread over metal by capillary attraction, to be an efficient lubricator under heavy pressure.

Kinnickinnic River Bridge on the C. & N. W. Ry. is a 234-foot double track swing span. About one-third the load is carried on a center-bearing, consisting of a phosphor bronze disc on a flat steel disc, each twenty inches in diameter. The pressure on the disc was only about 1,600 pounds per sq. in. When first put in operation the center ground so badly that the noise could be heard a mile away. It moved also with a jerky motion. We were using ordinary oil, such as is used for lubricating car journals. I received orders to jack up the span and take out the center, leaving the entire load to be carried by the outer live ring. I succeeded, however, in securing permission to experiment with this center, in an effort to reduce the friction. The discs were oiled by a ¾-inch pipe running through the center of the upper or bronze disc, which was grooved on the under side from the center to the circumference. I connected up this pipe with a barrel of kerosene oil by means of a rubber hose, and, opening the waste taps below, I had a flood of kerosene turned on whenever the span was operated. The kerosene soon cleared out the phosphor bronze scrapings, and the center operated under the kerosene without jar or noise.

With this data at hand I called on two oil experts and tried oils recommended by them, but without success. I then inspected a large number of oil samples in the laboratory of the Standard Oil Company. The oil I was seeking was one which would:

1st, flow freely like kerosene;

2d, spread on steel by capillary attraction;

3d, be free from acid.

I found such an oil, with the trade name of "Light Gravity Paraffine Oil." From the time when it was first used to the present the center discs have never ground except under temperatures of 20 degrees below zero, Fahr. and lower.

For wedge and other sliding surfaces, for treads and all surfaces open for inspection, I consider some of the various preparations of graphite the best lubricants.

In several cases, when swing spans with drums and wheels were turning hard, I have remedied the difficulty by oiling the tread. If the wheels always trained perfectly, no oil would be necessary, but this is seldom or never the case. Uneven expansion of the drum under temperature variations will throw the wheels out of train, and oil should always be used on the tread. Of course the oil on the treads collects and holds cinders, but the tread can be kept clean even when oiled.

Mr. C. F. Loweth: The writer agrees with the author that it is quite important that a turntable center should be securely anchored to but not necessarily set into the masonry. If the masonry is finished and dressed down to a true level for the center, it can be rigidly secured by anchor bolts, but these should be of large size, for anchor bolts to masonry are usually too small. There are a good many difficulties in properly setting a center in stone masonry or concrete, due to the work having to be done by different classes of workmen, or delays in getting the center set at the time the masonry is being built.

The track or lower tread should by all means be raised above the surface of the masonry. In large spans the width of lower tread or track is so great that it is impracticable to thoroughly tamp in material between it and the masonry, and the writer prefers to dress down the pier to an accurate level, and place the tread immediately in contact with it, securing it with large anchor bolts.

It is the practice of the road with which the writer is connected (C., M. & St. P. Ry.) to make water and dust tight floors on top of the ties over the turntable and the end lift machinery. This to a considerable degree keeps the machinery free from dust and dirt. It is also the practice to use lubricants only where absolutely necessary, depending on the frequency of operation, for the reason that lubricants catch the dirt and grit, and often result in more wear on the machinery than if allowed to run dry.

Mr. B. B. Carter: The writer agrees with Mr. Finley regarding the fastening of the rack to the pedestal on a horizontal line, and that it is not a good idea to use the foundation bolts for this purpose. It is unfortunately the case that the rack is often the weak link in the machinery chain, and without removable segments a breakage is serious. The nuts will often be rusted to the foundation bolts, making the removal of the rack difficult without loosening these bolts in the masonry. But he wishes to add that the rack-segments should also be centered and be held central by a turned vertical face on the pedestal.

At the Rock Island bridge, a slippage of the rack was observed due to the reversal of the forces, especially by the setting of the brakes. This bridge has a high acceleration and retardation load due to high speed. The writer's present practice is to cast bosses on the base of the pedestal castings, which are tapped for cap screws. Adjoining these bosses are slightly extended faces on the outer side of the tread circle of the pedestal. The bosses are faced, and the faces on the tread circle are chipped to the true circle. Corresponding bosses and faces on the racks being similarly fin-

Balance Wheel for Truss

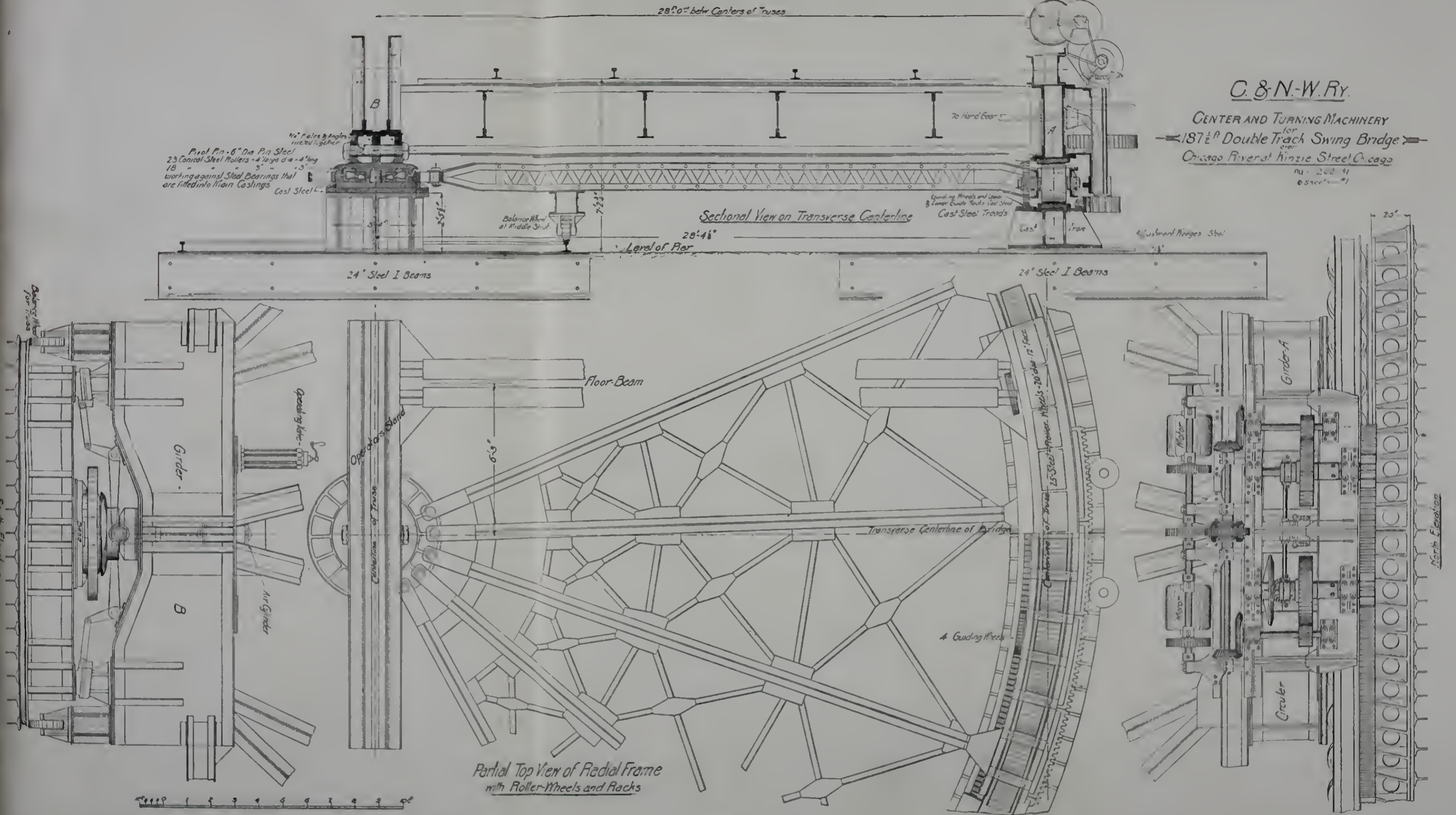

C. & N.-W. Ry.
CENTER AND TURNING MACHINERY for 187½ ft Double Track Swing Bridge over Chicago River at Kinzie Street Chicago
28' 0" betw Centers of Truses
B
A
¾" Plates & Angles riveted together
Pivot Pin - 6" Dia Pin Steel
23 Conical Steel Rollers - 4" large dia - 4" long
18 " " " 3" " 3"
working against Steel Bearings that are fitted into Main Castings
Cast Steel
To Hand Gear
Guiding Wheels and Upper & Lower Guide Racks Cast Steel
Cast Steel Treads
Cast Iron
Adjustment Wedges Steel
Balance Wheel at Middle Strut
Sectional View on Transverse Centerline
28' 4½"
Level of Pier
24" Steel I Beams
24" Steel I Beams
Balance Wheel for Truss
South Elevation
Girder
B
Operating Lever
Air Cylinder
Operator's Stand
Centerline of Truss
Floor-Beam
6' 3"
Transverse Centerline of Bridge
Centerline of Truss
15-Steel Roller Wheels - 20" dia - 12" Face
4 Guiding Wheels
Partial Top View of Radial Frame with Roller-Wheels and Racks
Girder A
Motor
Motor
Girder
North Elevation
20"

Fig. 14.

ished, it is impossible to erect the rack out of level or out of center.

At about every other vertical face fit, a key is fitted. Cap screws having the threads protected against dampness by the boss fits are not liable to rust in. The segments are joined in the usual manner by bolts. Thus arranged the racks are securely held in correct location, yet may be quickly and easily removed for replacement or repair, a segment at a time, without in any way disturbing the main foundation bolts. When these are once set, they should not be disturbed. The nuts on the foundation bolts are under the flange of the gear, space being allowed by the height of the bosses for the rack.

Mr. Loweth will recall the case of a certain bridge at South St. Paul, where the writer had considerable trouble and found that the rack was erected 5/8-in. out of center. These rack segments were located on a horizontal line, and held by the foundation bolts, but were not centered to the tread.

In regard to the question of radial rods, the writer believes that a great deal of the trouble from twisting and displacement of these comes from the fact that the shop has attempted to bore out a cored hole in a steel roller. This is a very difficult proposition, as anyone who has tried it knows, on account of the surface chill given by the sand. In several cases the writer has used the method of babbitting and boring these holes and with excellent results. He thinks a probable cause for the twisting of radial rods, is that the wheel and rod have become cemented together in the bore by rust. Babbitt is not subject to this trouble, and it is cheaper to make the fit this way.

In several cases the writer has used tangential rods running from the inner spacing ring to the spider ring; the wheels being spaced by a channel on the outside, and on the inside by a flat bar, with clips over the radial rods. In these cases no difficulty at all was experienced.

Referring to the concrete pier level which Mr. Cartlidge shows coming up to the top of the tread, the writer would look for cracking of the concrete where it is in contact with the tread, owing to the elasticity and working of the tread. The center casting can not be too carefully located and centered. In the South St. Paul bridge above referred to, the center was also out of line, and we had considerable difficuly getting it back into position.

Mr. A. F. Robinson: The writer is of the opinion that the difference between conical roller bearing centers and disc centers is largely a matter of cost. So far as turntables are concerned, we have been experimenting for a good many years, trying to get disc bearings for the centers, but have finally abandoned them for conical roller bearings. As a result of our experiments, we have a cone bearing which is not inexpensive but is giving us good results. The writer does not think, however, that these centers could be adapted to use on draw bridges without largely increasing their cost.

In regard to details of the track, wheels and rack, etc., the writer wishes to emphasize the necessity of designing these parts, so that a segment of the rack circle or any working part can be taken out of the bridge under traffic and between swings without having to take out any anchor bolts or having to disturb any of the machinery.

Mr. Albert Reichmann: The number of draw bridges on any single railroad system is comparatively very small, and the economy, therefore, in the first cost of light machinery is hardly worth considering. It seems to the writer that especial attention, in drawing specifications for draw bridge machinery, should be directed toward making it very strong, so that it will not be damaged by ordinary wear and tear.

It is also very important that draw bridge machinery when it is built, should be inspected by a good practical mechanical man, and it seems to the writer that the same man who has followed the work through the shop should have complete charge of the erection of the machinery. The men who generally look after this work are just ordinary bridge men, and there is not sufficient care exercised in putting these parts together.

We recently had some trouble on a large bridge from this very cause. A good man inspected the material in the shop and was satisfied that everything was all right, but the field inspector, who was not as familiar with machinery as the shop inspector, found trouble in putting it together, owing to slight inaccuracies which would have been easily taken care of if he had seen the machinery assembled in the shop.

All parts of the machinery should be so designed that they are readily accessible for repairs, and ample provisions should be made for adjustment, especially of all bearings, as these have to be carefully lined up.

Regarding conical rollers, they should by all means be put in a rigid frame or else they will bind, if not made perfectly true. On the other hand, if they are not made true at the start and begin to wear, owing to the fact that the unit pressure per lineal inch of roller is the same from one end to the other, the larger and the smaller diameters of the rollers will be reduced a like amount by wear, and the theoretical apex of the roller (formed by the elements of the cone) will move away from the center of rotation. As a result the inner end of the rollers will not travel at the same angular velocity as the outer end. Then, the wheels will skew and bind, unless the frame is sufficiently rigid to hold the wheels in their proper course. This trouble will not develop very readily, however, if ordinary good materials are used in the construction of the swing bridge.

Mr. Cartlidge objects to the use of cone bearing centers; the writer knows there has been a great deal of trouble with centers of this kind, as it requires a great deal of skill both to design and manufacture a cone bearing center that will give good service. In order to do this the cones should not be too long, and the angle of the cones should not be too great so that the end thrust against the bearings is diminished as much as possible. It is particularly essential, in order to obtain the least amount of wear and to ensure easy working, that the rollers and raceways for same, especially where they are carrying high unit pressures, should be of good material and properly hardened.

There has also been a great deal of trouble with phosphor bronze discs, owing to the fact that the engineers who order these parts do not always specify the proper composition for the phosphor bronze. As a result, in most cases, a poor soft material is furnished. It is the careful attention to these details upon which the successful operation of a structure depends.

Ordinarily our engineers think they have done their duty when they have drafted a set of general specifications and made a set of plans for a structure. The plans are turned over to the contracting company for execution and also to some inspection bureau, which in turn give their plans and specifications to their shop inspectors. Usually the inspection is let to the lowest bidder, and at a price at which no inspection company can afford to hire first class men. The poor inspector is given no leeway or authority, he rarely has seen the engineer for whom he is doing the inspection, nor has his attention been drawn to special features of the design that should receive careful attention;—there he is, a poor inexperienced man, who has had no mechanical experience, inspecting some great piece of engineering work of which he has absolutely no understanding. His judgment never becomes cultivated, no matter how long he sticks to the business, because he is never allowed to cultivate it. The writer would request all engineers, if they wish to make sure that their draw bridges and similar structures are properly constructed in the shop, to get in closer touch with their own inspector, and occasionally to take a trip to the shop and see how their work is being executed and what difficulties have been encountered in the shop. The idea of running your office on inspector's reports, is like carrying on war in Cuba with a typewriter.

We also have had trouble with phosphor bronze discs, owing to the use of lead in the alloy, which makes it too soft and naturally makes trouble.

In regard to the connections between the rack and tread, it is the practice of the American Bridge Co. to cast the rack segments right onto the tread, and setting the whole as one piece.

Mr. A. R. Eldridge: With reference to the practice of the C., B. & Q. Ry., of setting the center casting in concrete, the writer would add that concrete is the only form of masonry that we know anything about, in our present practice, and it does not delay the work at all to leave a hole for the center casting. We are not using cut stone any more.

The writer also believes that the method of connecting the rack directly by anchor bolts is better than the lug connection. The anchor bolts may be made of ample size, and when set in masonry, the holes filled with cement, and the holes in the tread casting filled with rust cement, as is done in our practice, there is absolutely no motion between the rack and the tread. Practically all the large swing bridges on the C., B. & Q. Ry. are built in this way, and none of them have given any trouble.

A great many of the defects which have been referred to in this discussion have been due to careless erection. A swing span is a piece of machinery requiring as careful adjustment in its bearings as any other machine of the same weight and size. If the same intelligence is devoted to the design of its parts, there will be little difficulty in its maintenance.

In view of the doubt expressed in this discussion as to the difficulty with radial rods, the writer can state that this difficulty is a fact and not a theory. In certain cases the rods have been twisted entirely off, and in others, which are still in existence, the rods have been twisted through a portion of a revolution. There is also frequent trouble through failure of the rollers to track properly or keep in line.

Referring to the cone center, our principal trouble has arisen through the impossibility of making any examination of the center, without jacking up the bridge. It was impossible to determine whether the rollers were turning or not, and in a number of cases it was afterwards found that the rollers were sliding and not rolling at all, thus leading, of course, to very hard action.

It is also unfortunate that the phosphor bronze for center discs, is generally so loosely covered by the specifications. Its composition and test requirements should always be fully set forth.

Mr. Andrews Allen: In regard to the turntable of the rim or rim and center-bearing swing span, the writer, while in the employ of the Edge Moor Bridge Company, about 1894, had charge of the design of the 240-ft., double track, combined center and rim-bearing span over the Calumet river for the Chicago, Lake Shore and Eastern Ry. The drum was very large, and the coning of the wheels was, therefore, very slight. The wheels were carried on adjustable radial rods and spaced by a channel on the inside, and by removable bars on the outside, as was the general practice at that time. The wheels, however, gave a great deal of trouble, owing probably to slight inaccuracies of workmanship or setting up. The difficulty was only remedied by bolting clamps on each rod just inside the wheels, in order to keep the wheels in line, and by the addition of tangential rods to keep the spider and live ring wheels together. Since this experience the writer has hesitated to use adjustable rods for turntables of any magnitude, and especially where the coning is slight. The stiff live ring used on the I., I. & I. R. R. bridge, illustrated in Fig. 9 was, the writer believes, one of the first, in the west at least, in which the adjustable rods were entirely done away with. Here was used a stiff channel frame with angles top and bottom between every other wheel connected to the spider. The wheels were carried on short axles on which the wheel was held to a working fit, so that it could not go in or out, by washers against shoulders turned in the axle. The whole axle carrying the wheel could then be moved in or out by means of a screw adjustment, until the wheel came to a perfect bearing. The axle was then locked by drilling in a cotter. Segments of the outside channel were made removable in case wheels had to be taken out. This design worked perfectly, and with slight modifications has since been widely adopted.

In regard to the center of a center-bearing span. The writer thinks that the question of adjustment is a very important one. He believes, however, in shim adjustment instead of adjustable rods or screw adjustment of any kind. After the bridge has been adjusted by the erector it ought never to be necessary to raise or lower the entire center, except in cases of pier settlement, in which cases the span can be jacked up and shims introduced between the center girder and the upper casting. The balance wheels may need adjusting, but it is a very simple matter to accomplish this with shims, as the wheels should carry no load, and even if some load should come on them, the bridge can be very easily and quickly jacked up sufficiently to take out a shim or two. We always allow plenty of leeway at every bearing point and provide plenty of shims for any possible variation of heights.

The Pencoyd design, in which the span is hung by adjustable rods, has many advantages, among which the most important seem to the writer to be:

First, the greater stability of the span while turning, owing to the construction of the center, which brings the center of support of the span as high, and therefore as near the center of gravity as possible;

Second, economy of height, as this center can undoubtedly be built in less vertical height than any other. The writer feels, however, that it may be open to criticism, on account of the uncertain distribution of load between eight or ten adjustable bolts.

The center wedges are driven to a firm bearing only, and it is always possible that this bearing may not be sufficient, or even that the wedges may occasionally not bear at all. The center girders and connections should therefore be calculated so as not to be seriously overstrained in such a contingency, and the writer, therefore, generally prefers, for shorter spans at least, the simpler construction in which the center girder or girders rest directly on the upper center casting, with shim adjustments at all bearings.

The writer has never noticed any lack of stability in the numerous spans which have been built in this way, and this construction certainly has the advantages of simplicity and cheapness to commend it.

The writer is also of the opinion that the importance of imbedding the center casting in concrete, as advocated by Mr. Cartlidge, depends largely on whether or not the center pivot carries any live or dead load. Most of the cases in which the center has been displaced have occurred in plain center-bearing spans, and it seems to the writer very necessary to imbed the center in this form of construction. Where, however, the center carries from ⅛ to 1-3 of the total load on the pier, it seems hardly necessary to do so, although even then, there is no possibility of making the center too solid.

NO. 3. DIFFERENT TYPES OF END LIFTS.

Mr. W. H. Finley: The writer does not consider the toggle end-lift shown in Mr. Cartlidge's paper a good one. Some years ago the writer looked over a certain bridge equipped with this end-lift, and noticed that as the ends were being raised, first one corner struck and then the other, the bridge vibrating from side to side until the ends were worked up to the proper height. Even then the ends were not properly raised, for when a train entered one end of the bridge, the other end was lifted off its bearings.

The writer greatly prefers the toggle and plunger end-lift as used on many bridges on the C. & N. W. Ry. to the end-lift shown by Mr. Cartlidge. Fig. 13 shows this lift as used on the Mississippi river bridge at Winona. This lift permits the absolute centering of the bridge, and holds it rigidly in position, at the same time allowing free longitudinal expansion.

This type of plunger end-lift is not new, and has been in use for a great many years. It is usually, however, hung with pins, while this design has knuckle bearings. The pins merely hold the different parts together and take no load. This construction avoids the wear and consequent lost motion of a pin bearing. The end-lift of the Winona bridge is operated from the center by means of shafting and spur gears which were substituted at the same cost, by the manufacturer, for the worm-gear mechanism originally planned. Ample provision, with grease cups and pipes, is made for oiling all working parts, and the writer has observed no loss of motion or wear on the working parts during the nine years in which the bridge has been in operation.

The Mississippi river bridge at Clinton is older and has a similar end-lift, except that it is connected throughout by pins, and operated mostly by worms and gears. This bridge has given considerable trouble from the wear in the pin holes and consequent loss of motion. There are numerous forms of end-lifts, and the writer quite agrees that "there is nothing new under the sun," but we do sometimes improve on what has gone before.

The rocker end-lift as used by the C. M. & St. P. Ry. and which was originally designed some 25 years ago by Mr. C. Shaler Smith for the Sabula bridge, seems to the writer to be the best form of end-lift with which he has had experience. It permits of expansion and contraction at the ends, is simple in operation and is highly efficient. The writer. however, prefers the form with rocker hanging inside the center bearing instead of as shown in Fig. 15. The entire machinery used on the Sabula bridge, as designed by Mr. C. Shaler Smith, is one of the most interesting examples of complete and perfect draw bridge machinery up to that time, and in many respects forms a very good guide for present practice.

The end-lift now in use on the Louisiana bridge of the C. & A. Ry.—a 400 ft. draw span—is essentially a nut and vertical screw. This lift was first used on the bridge over the Mississippi river at Winona—the bridge that preceded the one illustrated in Fig. 13.

The writer has had no experience with hydraulic end-lifts, and is not in a position to say anything about their efficiency, but there are a number of them in use, principally in the east.

In speaking of the rail lift, nearly every one uses a rail extending over the abutment, usually having a long mitred joint and lifted by levers connected to the end-lift. Mr. Cartlidge speaks of using a device that permits the rail to drop through a certain space, to insure its coming to proper bearing and alignment. The writer would question that practice as he has always found it necessary to use a positive method of drawing the rails into place. In hand-operated bridges he always uses a detector attachment that prevents the throwing home of the lever until the rail is in position. Some such arrangement as this is necessary unless you have a man at each end of the bridge to inspect the track before trains are permitted to cross. Our practice is to use mitred or lapped joints, which are much cheaper to maintain than butt joints.

For a number of years we tried, at Clinton, a device in which a short rail was made to slide across in contact with the rails on the bridge and abutment. This device, however, did not prove to be a success and was abandoned.

In general, the fact whether the bridge is to be turned thirty times a year or thirty times a day ought to be a factor in determining the type and design of the details of the machinery for its operation: and the writer supposes that all types of end-lift will still have their advocates. But it does not make any difference how perfect the end-lift may be, there must me intelligence used in the supervision of the bridge.

Mr. A. F. Robinson: The writer had the old Illinois River bridge on the A. T. & S. F. Ry. under observation for some years previous to its removal, and has watched trains passing over, when the wedges at one end would pull out so far as to frighten him. At one time the driving shaft was broken and one of the wedges fell into the river, in 30 feet of water.

Better results can be had from the use of toggles, or cams (as in the St. Paul, or C. Shaler Smith end-lift) than from any other type. In short spans the writer believes the cam to be the most convenient and economical. and for longer spans he prefers the toggle. which seems to give more positive results than any other design.

Our new Illinois River bridge is a 300 ft. single track draw span, with a very positive end-lift, consisting of heavy toggles with pin bearings. We can raise the ends of this bridge something like 1-5/8 in., and there never has been the slightest indication of uplift or pounding when trains run over it. The bridge is handled by one man and operated by a 24 h. p. gasoline engine in an overhead engine house. The machinery is interlocked with home and distance signals. and trains do not stop when they obtain the clear signal. This bridge has been in service about five years, and up to the present time has never caused an instant's delay to traffic. either on rail or water.

With reference to the connections between the rail on the bridge and on the abutment, use is made of "sliding blocks" on the Illinois River bridge previously referred to. The rails, both on the draw span and on the abutment, are cut off squarely at the face of the end ties, and rest on heavy steel plates. On the outside of the rails are sliding steel blocks which are planed to fit snugly to the rails. The outer ends of these blocks are slightly rounded so that there shall be no hesitation in their entering, in case the rails on the approaches may be slightly out of position. The top of this sliding block is about 1/4 in. higher than the top of the rails. When the blocks are in reasonably good order, you will very seldom notice any clicking sound when trains are passing, and the trains go over this bridge very fast. The rail blocks must be very hard. The first set was made of medium steel and lasted only eight or nine months. Since then the blocks have been made out of old locomotive tires, and one set of these blocks lasts about two years.

This bridge stands about northeast and southwest, so that one side gets the sun nearly all of the day. Up to the present time. however, there has been no trouble from the bridge warping or twisting out of shape. The toggles enter pockets with sloping sides. so that the span is always brought to perfect line, and longitudinal expansion causes only a little sliding friction. If the operator notices that the span is warming up, he will loosen the toggles once in a while and then drive them home again as to let the span adjust itself.

Mr. C. F. Loweth: Provision for expansion and contraction at the ends of swing spans is frequently overlooked. This is a matter of small importance in short spans. but where they are three hundred feet or more in length it becomes important. Where the bridge is opened several times daily. expansion or contraction of the trusses is adjusted each time the bridge is opened. but there are many draw spans which are rarely opened, sometimes never during the winter months, and in these the strains due to the absence of provision for temperature stresses must be considerable.

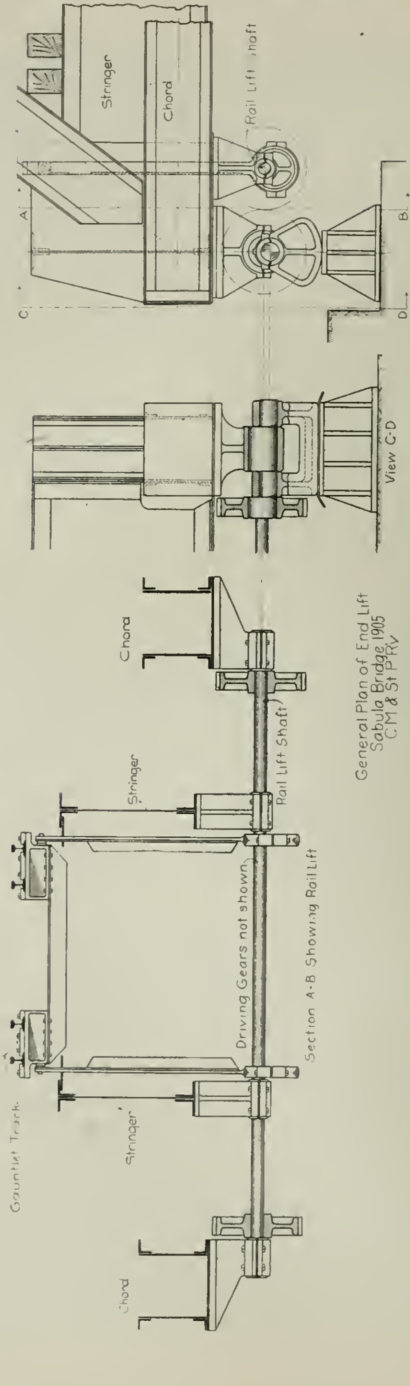
The design of end bearing which has been the standard practice with the Chicago, Milwaukee & St. Paul Railway for a good many years past, provides fully for expansion and contraction, and the writer believes is a much more satisfactory detail and less liable to get out of order than any he is acquainted with. This end bearing consists of a segment of a rocker, swinging freely from an eccentric shaft or cam hanging or supported at the ends of the trusses. This eccentric shaft is operated by suitable gearing, and in turn raises or lowers the rocker. The action is positive, and the design is simple and compact, as shown in Fig. 15 and by the half-tone cut, Fig. 16.

This form of end-lift, the writer thinks was first used on the bridge over the Mississippi River at Sabula on the C. M. & St. P. Ry. of which Mr. D. J. Whittemore was chief engineer and Mr. C. Shaler Smith consulting engineer. This bridge has recently been removed, after having been in service about twenty-three years, during all of which time the end-lifts worked satisfactorily.

The writer does not agree with Mr. Finley in his criticism of the end-lift shown in the paper, and believes it to be more satisfactory than toggle joints; yet, he does not consider it satisfactory in that it seems a very unstable support. The writer remembers seeing a large draw span with a toggle end-lift, operated crosswise to the bridge, in which the ends of the bridge had not been lifted high enough to permit the three joints of the toggle to come in the same vertical plane, and when a train came on the bridge the thrust of the toggle broke some part of the mechanism, causing the vertical screw by which the toggle was operated and held, to come up through the floor, resulting in a serious derailment. Since that time he has been afraid of toggle joints for end-lifts for swing spans.

The writer has built a number of swing spans with end-lifts similar to that shown by the author, and has always considered it necessary that the rollers should be pushed out somewhat beyond the center plane of the trusses, and against a positive stop on the outside, so that the roller can go so far and no farther. This makes the links batter slightly outward from the truss, and results in a more stable support than where the links are truly vertical. But at the best the lateral stiffness of the bearing cannot nearly equal that of the Sabula type of rocker bearing.

The writer takes exception to the author's statement where he refers to end rails as being allowed to drop into position. The writer thinks the rail-operating mechanism should not only lift the rails but pull them back into their proper places. They may get caught and fail to drop into place, and it is not safe to depend on the bridge tender to see that all the rail ends are down. In



General Plan of End Lift
Sabula Bridge 1905
C M & St P Ry

Fig. 15.

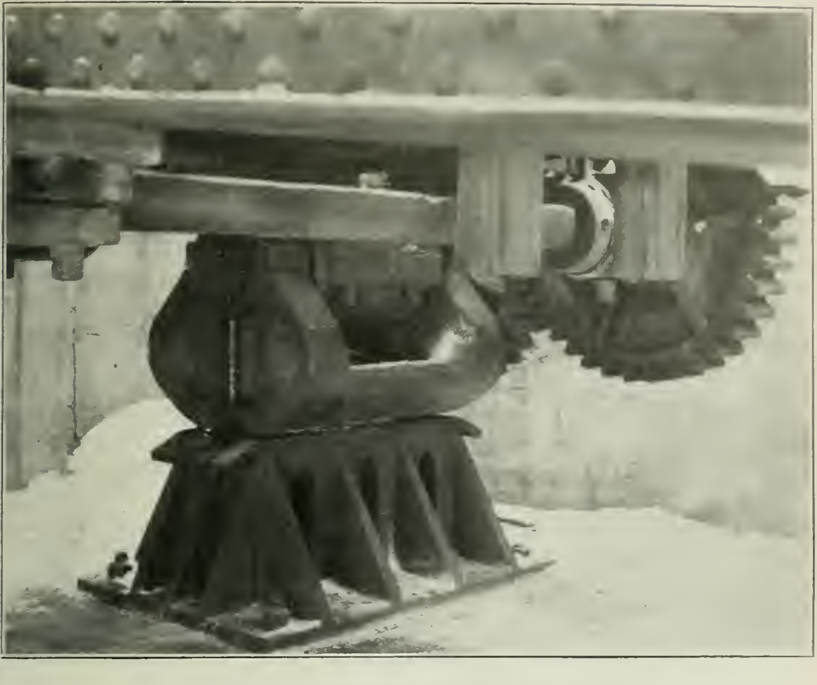


FIG. 16—CAM END LIFT—USED BY C. M. & ST. P. RY.

many cases with frequently operated bridges there are not attendants enough, nor time enough, to make sure by actual inspection that the rails are in proper position: The mechanism should be such as will call the operator's attention to anything which prevents the rails being pulled back into position. Where the draw is interlocked with distant signals, the mechanism should be such as will insure the rails being in place before the signals can be changed. For some time past, the practice on the road with which the writer has been connected has been to use lapped or bevelled rail joints at the ends of drawbridges, the joint coming over the back wall of the abutments, and it is believed that this form of joint, with positive operating mechanism, such as above described, is a desirable and safe arrangement. The square joint is hard to maintain, and is very hard on the supporting structure.*

Mr. A. Reichmann: The end-lift illustrated in Mr. Cartlidge's paper is open to the objection that it comes to a full stop when driven home. The writer thinks that in power-operated bridges there should be no positive stop to the end lift; such a stop can do no good, but only endangers the machinery should the engineer run past the indicator. In the case of the Sabula lift, the motion of the shaft may be continuously in one direction, and the lift may be driven and released without reversing the engine. The main trouble with most end-lifts comes from failure to provide sufficient power.

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*The above remarks as to rail joints were made at the meeting April 18 or May 16, and previous to the Atlantic City draw-span disaster, which brought out the necessity of what the speaker here refers to.

Mr. B. B. Carter: The end-lift is a most interesting problem. The St. Paul or Sabula lift is nearly ideal for short spans and short lift. It is open to the objection of not centering the bridge or holding it central. If arranged to center, the wedge sides cause the necessity of extra lift to clear in swinging. This increasing the throw of the eccentric, materially affects the power required as well as the size of parts.

It does, however, allow the bridge to shrink or stretch by temperature changes or stretch from the live load without throwing a longitudinal load on the masonry. The efficiency of an eccentric is very low and for heavy lifts the power requirements are too high.

For medium long spans and rather high lifts, but with medium live and dead load reactions, the writer prefers the Morrison lift as shown by Mr. Cartlidge. He, however, adds a diaphragm between the vertical links, using only two links, the top of the diaphragm being bored to fit the upper pin. This increases the bearing surface on this pin. The lower pin is keyed to the link, thus forcing the roller to turn on the pin.

This lift, forces and holds the bridge to an absolute center and insures the alignment of the track for any form of rail junction. It does have the objection of not providing well for the longitudinal movement of the draw span, and does throw a load in this direction on the masonry. It is exceedingly efficient, and, when well connected, operates very well. Its frictional resistances are low when properly designed and built. The operating by a slow-speed longitudinal shaft is poor practice, especially when below low iron, as shown in Fig. 3. It is better when using a longitudinal shaft to have this a high speed shaft, and hence a small one, with a reduction train of gearing near the lift. It is impossible to have or keep a longitudinal shaft in line, and a heavy shaft introduces a high friction load from its own stiffness. Pneumatic or hydraulic operation for this form of lift is very efficient and eliminates the shaft problem.

On the Rock Island bridge there was used the general form of end-lift illustrated by Mr. Cartlidge. The end floor beam was doubled, and the low iron of the bridge was not infringed upon by a shaft, as in the case in Mr. Cartlidge's illustration. In the center there was a double toggle, connecting back to an air cylinder. When the ends were raised the center toggle overlocked ¼ inch. The end lift on the Rock Island bridge had the worst possible conditions to contend with, due partly to unequal temperature deflection, which amounted to about ½ inch. One set would go up free and compel the other set to work under double deflection. Some difficulty was experienced from this cause, but after correcting this the machinery worked well and has given no trouble.

But for very heavy reactions and high lifts, on long and heavy spans, with heavy live loads, the writer prefers the double toggle with plunger. This form is designed for the large bridges to be put in near Portland, Oregon. In these cases the plungers will rest on regular expansion bearings fixed to the piers. The longitudinal movement due to the maximum load but not including that due to temperature changes will be about one inch on each end of the draw span. These toggles will be operated by electric motors with automatic stopping devices, through a train of gearing and toggling cranks at each end. The toggle cranks will overlock ½ inch, but the toggles will be set with all the pin centers in line. The toggle pins are small, being used only to hold the toggles together, the bearing being in large cylindrical seats.

The centering is done with plugs attached to the center of the toggle through the end post bracket, entering sockets in the ends of the lower chords of the adjoining spans. The writer thinks the form of end-lift, as well as all other machinery, should be in conformity with the size, weight, cost and importance of the draw on which it is intended to be used, and further that no end-lift yet devised is best for all conditions.

Regarding the rail lock, the kind shown in Fig. 3 has nothing to commend it except cheapness of first cost. This is often given too much consideration.

The rail or ties must be loose from the bridge for some distance back, and even then only transfer the rail gap to some other place on the bridge. If the rails are scarfed or slit joined, there is danger of their not seating, and does not entirely overcome the gap or end wear. The mere fact that they have to be dropped and thus hammered into place shows their unreliability.

The form described by other writers, with a key sliding along the side of the rail on the outside over the gap, with the top tapered so that at the gap the elevation is about ¼ inch, such as is used on the Rock Island bridge, is almost perfect. There is no wear on the ends of the end rails, no pound on the bridge or masonry, and the gap can be crossed at almost any speed without danger or even being noticed on the train. This has been used to the writer's knowledge on many bridges lately built with unfailing success. However, the key must be locked in the forward position to prevent the tractive force of the locomotive withdrawing it.

Mr. A. H. Eldridge: Mr. Finley has stated in his discussion that the end lift of a certain bridge, which was built after the plan shown by Mr. Cartlidge, when in operation came to bearing first at one end and then at the other, the span vibrating until it finally came to the proper height. The writer considers the criticism wholly immaterial. It is difficult to conceive of any end lift that will not allow the same thing to occur when, for instance, one side of the span is heated and the other cool. The all important mission of the end lift is to raise the ends so that there will be no pounding, and if this is done regularly, under all conditions, we ought to be satisfied.

If Fig. 3 of the St. Croix swing span be carefully examined, it will be found that the bearing of the ends is not a linear bearing, but that both upper and lower castings bear on the arc of a cylinder.

The writer had hoped to personally inspect the two C. B. & Q. draw spans under discussion, but has been unable to do so. He asked the Bridge Superintendent, however, under whose care they are, to make a complete report on the principal points under discussion. His report is as follows:

> "DEAR SIR: In answer to yours of the 8th.
>
> As to the ends of the Winona and St. Croix draw bridges moving up or down, or moving in any way, while trains are passing over draw, must say that I make frequent tests in regard to this under various conditions of temperature, and I have always found that the ends are perfectly rigid, under all conditions.
>
> As to the ends lifting unequally. This depends somewhat on the position of the draw span with reference to the sun at various times of the day, which will cause an unequal expansion which causes a temporary variation in the elevation of the four end bearings when draw span rests on center bearing. This, however, is very slight and not enough to cause any trouble.
>
> We have had no trouble on account of expansion.
>
> Taking it as a whole, the working of the Winona, and more particularly the St. Croix draw, which is of a little more modern design, is very satisfactory. In my opinion it is far above anything I have seen on other lines."

Mr. Andrews Allen: The problem of designing an end lift is not a simple one. A draw bridge is very sensitive to temperature changes and both vertical deflection and lateral alignment is often very greatly affected. In actual practice it is very seldom that any two of the four end bearings are at the same *level* or *line* when the end lift starts its operation, and the end lifts has to take each corner bearing wherever it finds it, and work it up quickly and positively to the proper height and line, irrespective of the condition of the ends. For this reason the writer does not believe in any sliding lift like the wedge or like the one illustrated in Mr. Cartlidge's paper being operated across the bridge, for when one side strikes before the other, there will be lateral displacement and consequent vibration, wear, and difficulty in centering. The toggle or screw work vertically, and can be operated either laterally or longitudinally, but the wedge or cam should be operated longitudinally.

Any of the end lifts mentioned in the paper and discussion, when properly designed, will lift the ends satisfactorily. It is simply a question of good mechanical engineering. You can do it with a cam, wedge, or toggle, and the actual power required does not vary as much as one would think. As an illustration of this, the writer recently made a very careful comparative design and estimate of a "wedge" and a "cam" end-lift on the St. Paul plan, for a 210 ft. deck plate girder draw span. Both of these lifts were designed to fulfill the following conditions:

	Inches.	*Pounds.*
Normal end lift,	1.25	24.000
Possible temperature variation,	1.5	29.000
Total lift,	2.75	53.000
Clearance,	.75	
Total vertical motion,	3.5	

On this basis the main wedge shaft developed a maximum torque of 185,000 inch pounds for a total rotary motion of 90 deg. and the cam shaft developed a maximum torque of 112,000 inch pounds for a total rotary motion of 135 deg. Assuming the total power proportionate to the maximum, the power required to drive the wedge would be only 10 per cent more than to drive the cam. This difference, in a small bridge at least, is entirely immaterial. The relative cost was also analyzed with some care, and the wedge was adopted.

The importance of an effective method of horizontal centering is frequently overlooked. Some swing bridges are so located that they do not warp very badly from the sun's rays, but the I. I. & I. bridge, illustrated in Fig. 17 used to get more than six inches out of line from this cause. The original wedges were not figured for such a great horizontal deflection, and we finally had to replace the wedges and upper castings with new parts designed for a horizontal as well as vertical wedge action. With the new wedges the Chief Engineer recently informed the writer they have no difficult in centering the bridge horizontally, and in raising the ends 1-¼ inches in accordance with the plan.

For smaller bridges as shown in Fig. 18 we set two heavy steel pins into each base casting with just room for the wedges to work between them. We then give the nose of the wedge a sufficient amount of horizontal taper to enter and force the bridge to alignment under all conditions, and we never have any difficulty in centering or raising the ends.

The toggle lift, also the lift illustrated by Mr. Cartlidge, are both designed to center the span very positively. The St. Paul cam lift is, however, defective in this respect, and there seems to be no way of centering the bridge with a cam lift, except to key a heavy cast steel arm on the cam shaft, so arranged that it will slide against the edge of the base casting, which should of course

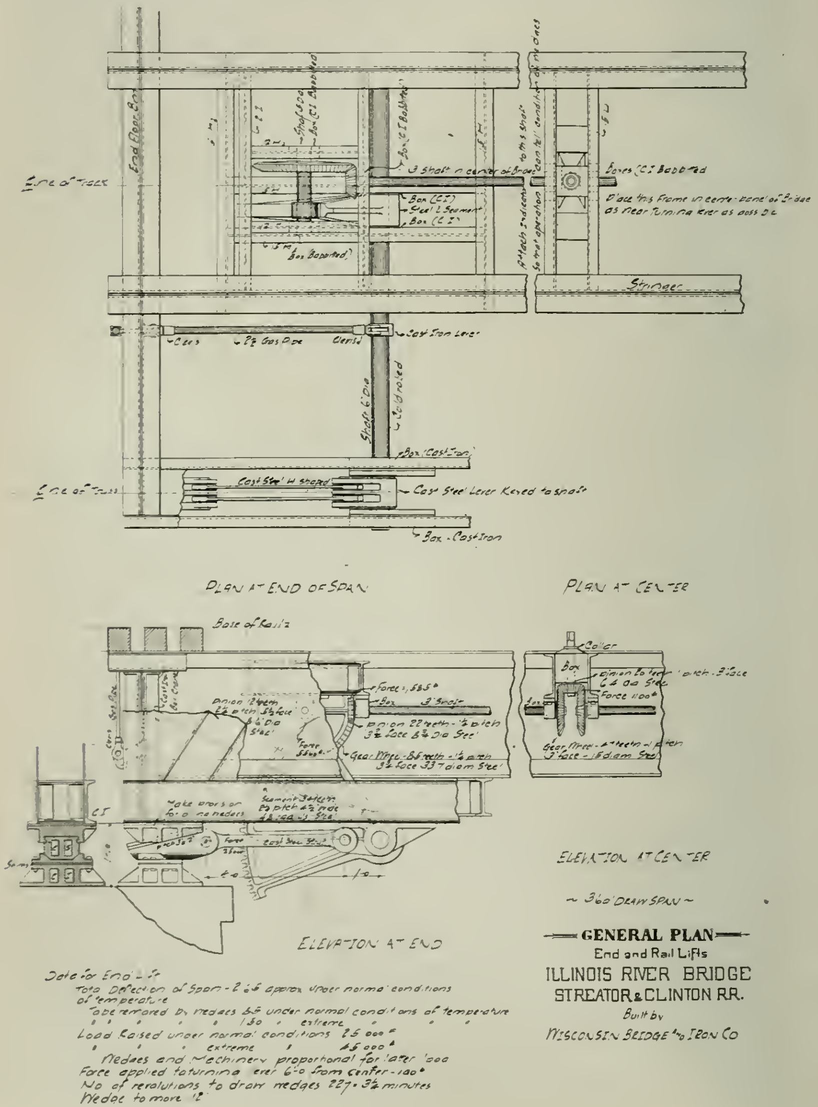

End Floor Beam
Line of Track
Shaft 5 Dia
Box (C.I. Babbitted)
Box (C.I. Babbitted)
3 Shaft in center of Bridge
Box (C.I.)
Steel L Segment
Box (C.I.)
Box Babbitted
Attach Indicator to this shaft so that operator can tell condition of wedges
Boxes (C.I. Babbitted
Place this Frame in center line of Bridge as near Turning Lever as possible
Stringer
Clevis
2½ Gas Pipe
Clevis
Cast Iron Lever
Shaft 6 Dia
Cold rolled
Box (Cast Iron)
Line of Truss
Cast Steel H shaped
Cast Steel Lever Keyed to shaft
Box - Cast Iron
PLAN AT END OF SPAN
PLAN AT CENTER
Base of Rails
Pinion 12 teeth 2½ pitch 5½ face 8½ Dia Steel
Force 1,585
Box
3 Shaft
Pinion 22 teeth ½ pitch 3½ face 8¾ Dia Steel
Force
Gear Wheel - 86 teeth - 1¼ pitch 3½ face 33.7 diam Steel
Make provision for oiling wedges
Segment 36 teeth 2½ pitch 4½ wide 48 rad Steel
Cast Steel Strut
Collar
Box
Pinion 20 teeth pitch 3 face 6.4 Dia Steel
Force 1100
Box
Gear Wheel 44 teeth pitch 3 face 15 diam Steel
ELEVATION AT END
ELEVATION AT CENTER
~ 360' DRAW SPAN ~
GENERAL PLAN
End and Rail Lifts
ILLINOIS RIVER BRIDGE
STREATOR & CLINTON RR.
Built by
WISCONSIN BRIDGE AND IRON CO
Data for End Lift
Total Deflection of Span - 2.65 approx under normal conditions of temperature
To be removed by wedges 6.5 under normal conditions of temperature
" " " " " 13.0 " extreme " " "
Load Raised under normal conditions 25 000
" " " extreme " 45 000
Wedges and Machinery proportioned for latter load
Force applied to turning lever 6-0 from center - 100
No of revolutions to draw wedges 227 - 3½ minutes
Wedge to move 12

Fig. 17.

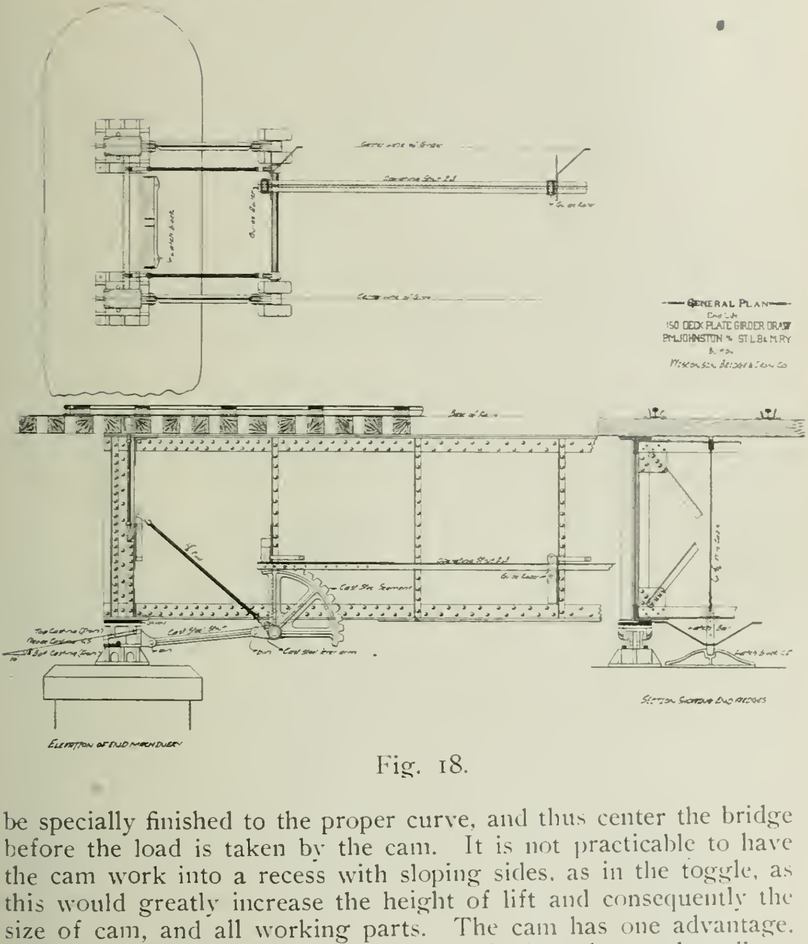

GENERAL PLAN
150 DECK PLATE GIRDER DRAW
P.M.JOHNSTON & ST.L.B.& M.RY
Wisconsin Bridge & Iron Co
Cast Stl. Segment
Cast Stl. lever arm
Top Casting
Bot Casting
ELEVATION OF END MACHINERY
SECTION SHOWING END RESTS

Fig. 18.

be specially finished to the proper curve, and thus center the bridge before the load is taken by the cam. It is not practicable to have the cam work into a recess with sloping sides, as in the toggle, as this would greatly increase the height of lift and consequently the size of cam, and all working parts. The cam has one advantage, however, over all other forms of lift. It is the only one that allows longitudinal expansion of the span without developing sliding friction. This is an advantage to the masonry, particularly as the masonry in this case does not receive horizontal vibration under the passage of a train. Next in merit on this question comes the wedge, where we have sliding friction on a flat bearing. The toggle or any other lift sliding on a grooved or curved recess develops greater frictional resistance.

The wedge has a bad name, owing to the disgraceful way in which it has been misused. It is often operated by rods and levers in such a way that the power decreases as the load increases. It has been frequently placed with its top surface horizontal, so that the height of the ends of the bridge is constantly changing from temperature expansion of the span.

The writer greatly prefers to operate the wedge by means of a toggle lever keyed into a transverse shaft, this shaft in turn being operated by a segment gear, which can be operated either by beveled gears, where a longitudinal shaft is used for power operation, or by an operating strut with pins meshing into the gear teeth. The cut of the Illinois river bridge, Fig. 15 showing the first method and Fig. 16 showing design of deck plate girders, shows the second method. Both of these methods multiply power very fast toward the top of the lift, and both have given perfect satisfaction.

The writer confesses to a great preference for the wedge, and this preference has been increased by examination and analysis of other forms of end lift. Any end lift, as stated above, can be designed to raise the ends, hence it is a question of maintenance and first cost. The wedge is admittedly much cheaper than any other lift, with the possible exception of the St. Paul cam. It can be made just as efficient as any of them and with little more power; it has fewer parts, and those parts are heavy and simple. *No working parts carry live or dead load,* and the wedge makes a substantial bearing, approximating more closely than any other, the bearing one would use under a fixed span.

Mr. J. W. Schaub: In regard to the end lift, there is no doubt that the amount of work necessary to raise the ends of a bridge is the same in any case, and the effort would also be the same in case the work was uniform and the friction of the moving parts was equal. The difficulties to be looked for, must then be in the details. Another difficulty, which is usually ignored and which becomes apparent in special cases and in long spans, is the lack of a free movement at the ends of the span due to changes in temperature and the longitudinal force due to the friction on the track rail. In all kinds of end lifts, known to the writer, with one exception no provision is made for this movement except by permitting the ends of the span to slide back and forth over the abutment. This becomes a serious matter in long spans that are opened very rarely. In one case where this movement was transmitted to the abutment, the latter was free to move towards the center pier only, the abutment being prevented from moving in the other direction by a high bank of earth behind it. This movement in one direction, due to changes in temperature and the dynamic action of the moving load, resulted in the abutment being pulled out of position to such an extent as to finally prevent the bridge from clearing the back wall. That the real cause of the trouble was due to this fault in the design was proven in this case by overcoming the entire difficulty by means of a nest of rollers placed under the ends of the span. The end lift above referred to, which provides for a free movement of the ends of the span at all times, is known as the Sabula end lift, being first used by the late C. Shaler Smith on the bridge over the Mississippi river at Sabula, over twenty-five years ago. This consists of a segment rocker hung from an eccentric shaft or cam at the ends of the span. When the eccentric shaft is turned, the ends of the span are raised or lowered by the amount of eccentricity of the shaft. This mechanism acts quickly with a practically uniform effort of the prime mover. It is cheaper in shop work than the usual form of wedges, as the work is largely done on a lathe, whereas the wedges require the work done on a planer. It weighs less when finished than any form of end lift known to the writer which actually lifts the ends of the span. To be sure there have been many swing bridges built in the past with end lifts, which do not lift, and the writer has had occasion to remove some of these monstrosities, for which some one was awarded the contract because they made a lower price than others, and in each one of such cases he has introduced the Sabula end lift to advantage.

In regard to the rail lift at the ends of a swing span, shown by the author, Fig. 3, this form of mechanism has received a terrible indictment by the recent disaster at Atlantic City on the Pennsylvania R. R., where sixty-seven lives were sacrificed through using a form of mechanism which may or may not be safe to the passage of a train, and which will permit a signal at the same time to show safety. This form of mechanism is so well known, and has so recently been illustrated and discussed in connection with the Atlantic City disaster that it is not necessary to describe it here. It should suffice to say that it should be banished forever, as it is the most dangerous piece of mechanism ever used on a bridge. It might be argued, as the *Engineering News* in a recent editorial argued, that if the rails had been held down fast to the lifting mechanism they would have returned to their proper position in the track. There is nothing positive about this; for, if the rails are made fast to the lifting mechanism, and the rail is lifted out of its socket, it does not follow that this rail will return to its place, when in the meantime some obstruction has fallen into the socket. Now what can happen? The rail is being pulled down into place, when, first the connection between the rail and the mechanism may fail, or second, the rail may spring enough out of line to permit the mechanism to show safety, whereas the worst possible danger may exist. In the place of the rail lift, the writer uses a rail wedge, or movable rail splice, which makes a continuous joint for the rail, and at the same time enables this movable splice to be interlocked so that the same cannot be out of place without showing the signal at danger. Another advantage in this form of rail splice is that it makes a continuous support for the wheels passing over it, and thereby does away with the hammering on the ends of the rails and all of the bad effects produced by this impact on the rails at high speeds. This is the ideal rail splice for the ends of a swing span, and strange as it may seem, this form of rail splice has been in use on the Delaware river bridge of the Pennsylvania R. R. since 1896. The original design for this bridge called for the usual rail lift. This was tried with square ends, and also with scarfed ends for the rails, and proved entirely inadequate to stand up under the high speed trains which cross this bridge at full speed. After this, the present form of rail wedges were adopted, which are interlocked with the distant and home signals, forming one of the finest examples of swing bridge signalling and interlocking in this country.

Mr. F. C. Kunz, (read by Mr. R. E. Belknap): Mr. Cartlidge objects to the wedge lifts at the ends and prefers toggle lifts. We do not share this preference and use in our own designs, wedge lifts, and toggle lifts only in cases where the Railroad Companies expressly desire it; this, however, happens very seldom. Of the bridges named on a previous page, only the two with a combination of rim and center bearing will have toggle lifts. The wedge lift is more substantial, therefore less apt to get out of order, and gives to the live load passing over the bridge, with its impact, a greater bearing area than the toggle lift. To furnish the necessary lifting of the ends is merely a question of multiplication of machinery.

Mr. F. H. Bainbridge: Of the details shown by Mr. Cartlidge, the writer considers the end lift device shown in Fig. 3 inferior to some other types of lift in common use. His objections are the following:

First, It makes an unstable support when the ends are raised.

Second, The centering of the span is not complete until the ends are raised. This makes a large frictional resistance against centering. The centering device should be controlled by sufficient power to straighten out a span when warped by the sun. The writer has watched the action of a similar device on the C., B. & Q. Ry. span over the Mississippi river at Winona, Minn. This span was designed and built under the direction of the late George S. Morison. The span is 360 feet in length from center to center of end bearings, and when closed for trains the center line of the bridge bears east and west. On a sunny day the distortion is so great that this centering device will not overcome it. The operator has frequently to keep the span turned toward the sun, closing the span for trains.

Third. The large number of small pins is objectionable. The pins, as well as their bearings, wear and make loose mechanism and lost motion.

Fourth. The nut and screw device in Fig. 3 is, mechanically, of low efficiency.

Fifth. The operation of this lift in practice is such, as at times to severely jar the bridge. A link roller on one side will strike first, the shock throwing the end of the span back to the other side The writer has observed this defect on the span at Winona mentioned above.

Sixth. This type of lift does not provide for the longitudinal expansion and contraction of the span under temperature changes and load.

The best type of end lift, in the writer's opinion, is that in use on the C., M. & St. P. Ry. It originated in the designs of the late C. Shaler Smith. It consists essentially of a rocker bearing raised and lowered by the eccentric motion of an offset shaft. As usually built, this lift does not provide for centering the span, the centering being done by a separate device, but by bevelling the edges of the cam to correspond with a similar bevel in the end bearing casting, the centering could be accomplished by the lift itself. The good points in this type of lift, as the writer sees them, are as follows:

I. It provides for longitudinal movement due to temperature changes and load.

II. As compared with a wedge or toggle, its efficiency is high.

III. It can be operated entirely by direct spur gearing.

IV. It gives a rigid support.

V. There are no small pins to wear loose. The shaft carrying the rocker is held in adjustable boxes.

The theoretical advantages of this lift can be observed in practice. The writer has watched the operation of three or four spans equipped with this device, and has invariably found that the ends were sufficiently raised to prevent hammering, and the machinery operating the lift, worked entirely without jar.

Mr. Schneider: The writer does not agree with the author that the difficulties in the way of getting adequate lift with wedges are too great. That the wedges on some of his bridges did not lift sufficiently is not on account of the inadequate power of the engine, but on account of faulty design. The end lift shown in Fig. 3 is one of the oldest devices, first used by the Phoenix Bridge Co. over thirty years ago. The writer has also used similar lifting arrangement in the earlier designs of swing bridges, but discarded it more than a score of years ago, because by properly designing the machinery for moving the wedges he could get all the advantages of the roller lift and besides gain the additional advantage of more substantial supports. This is shown in Fig. 12.

Mr. C. L. Strobel: Mr. George S. Morison's end lift and locking arrangements, with the author's improvements, are no doubt fairly satisfactory, but the writer prefers a locking device that consists of a plunger with beveled lower end fitting in grooved bearings to correspond, and free to slide longitudinally with the temperature motion of the bridge. This plunger is moved vertically and is actuated by a longitudinal shaft and a double toggle. There is a latch or horizontal bar that moves outwardly from the movable span and fits in a socket anchored in the abutment. This latch, which is connected with a spring, holds the span primarily. The plunger adjusts it more accurately in position and locks it finally. The temperature movement of the span takes place by the sliding of the plunger-end in the grooved bearing. As the ends of the span are lifted only enough to prevent rattling at the far end as the train passes on the bridge, sliding friction is not objectionable except for very long spans. The plunger is held low and in a very substantial manner by gusset plates riveted to the lower chord and end post.

For locking the rail the writer prefers an arrangement that avoids the lifting of the rail. The rail is cut between the abutment and the swing span, and the space that must be left for expansion between the rail ends at this point is bridged over by a forged or cast steel tongue fitting close against the outside of rail and moved forward from the swing span. This tongue also locks the rail. The details here described are shown by Fig. 19.

4TH.—POWER OPERATION.

Mr. W. H. Finley: The question of motive power is a most important one, and depends largely on local conditions. The C. & N. W. Ry. was the first to use the gasoline engine, and now operates draw bridges with gas, gasoline, steam, electric and hand power. Unquestionably electricity is the best if it can be obtained reliably and without trouble. As Mr. Carter says, it is more elastic, and with it, it is possible, to develop better designs and better details in the machinery.

The Kinzie street bridge, shown in Fig. 14, is one of the busiest draw spans; it is a double track span, makes about 100 turns in twenty-four hours, and is operated by electric motors and compressed air. The electric motors are used to swing the bridge, and the compressed air to drive a very powerful latch, used for centering the bridge, and to lift the rails. There are no end lifts, the ends running up on rollers; this construction is used in order to minimize the time for operation, on account of the great number of trains passing this bridge. The center is also very unusual in types—the span pivoting on a conical roller center under one truss, the other truss resting on a segment of drum and wheels. There are wedges to carry the live load under the pivot side of the center, and these wedges are also operated by compressed air.

The first of the C. & N. W. Ry. bridges operated by gas was a 235 ft. double track swing span over the Milwaukee river at Milwaukee, and to Mr. E. C. Carter, chief engineer of that road, is due the credit of first adopting gas or gasoline power for the operation of this bridge. This bridge has been in service about fifteen years, and has given excellent satisfaction.

The C. & N. W. Ry. bridge over the Kinnickinnic river (230 ft. double track swing span) is also operated by a 20 h. p. gasoline engine, and has also given good satisfaction. The writer might mention the fact, that the fire tugs of the Milwaukee Fire Department are located just above this bridge. When the first alarm is sounded the fire tug starts out under full head of steam, and never

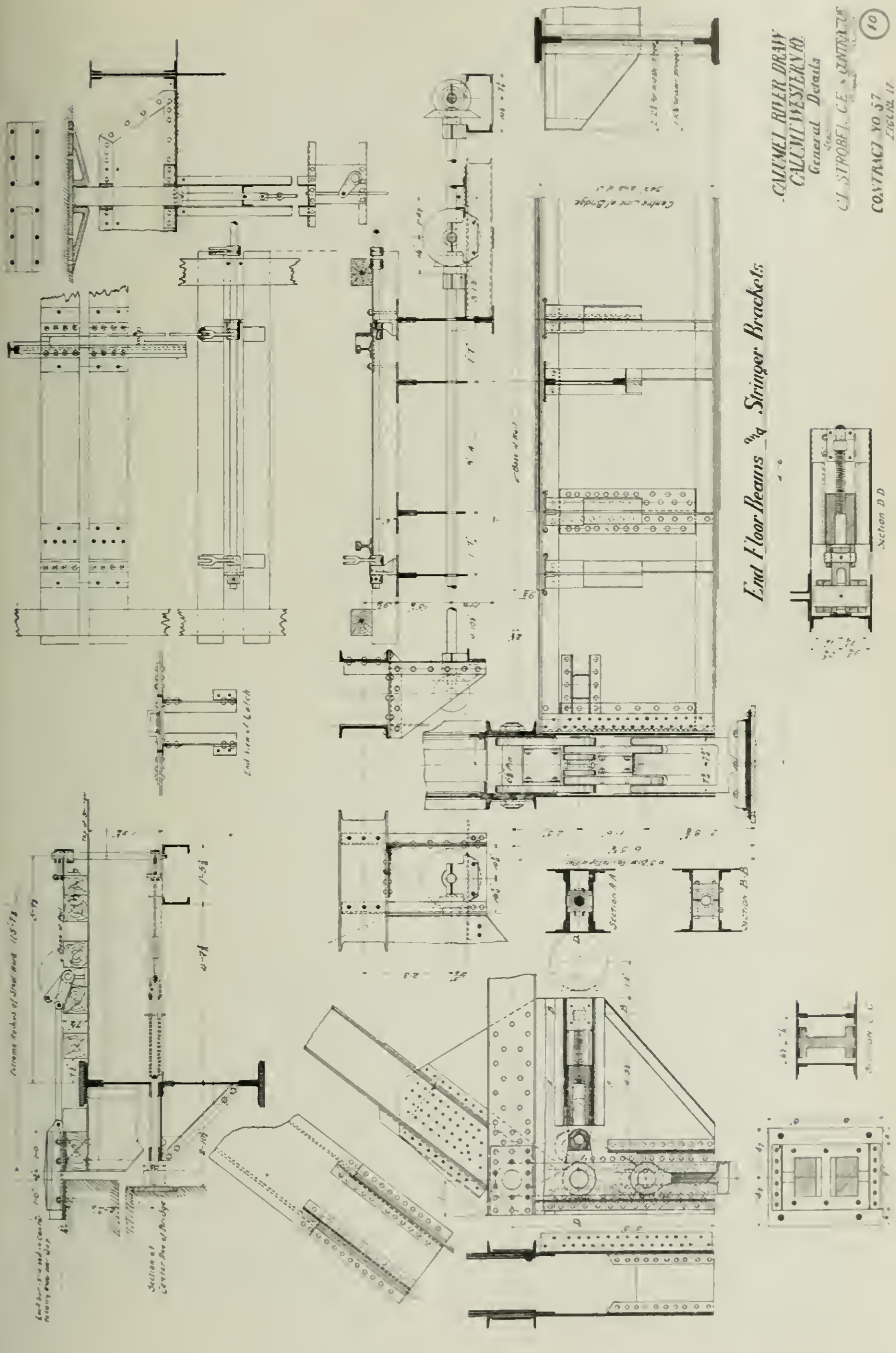

CALUMET RIVER DRAW
CALUMET WESTERN RR
General Details
C.L. STROBEL, C.E.
CONTRACT NO 57
FIGURE 11
10
End Floor Beams and Stringer Brackets
Section DD
Section AA
Section BB
End Lift and Latch
Centre Line of Bridge

Fig. 10.

yet has there been any trouble in clearing the channel for this purpose. There have been no accidents, and the bridge has always opened when required.

The Winona draw span (360 ft. single track) is swung by a 36 h. p. gasoline engine, and was originally operated in about forty-five seconds. This, however, was too fast for the bridge, and the speed has been cut down.

The draw span over the North Branch of the Chicago river at Deering is a double track span 176 ft. long, and is operated by steam. It does not turn very often, so that the cost per swing, tabulated below, naturally runs high.

The cost per swing, and the number of swings per year, of the principal draw bridges of the C. & N. W. Ry. has been carefully collected and is here presented. These costs include fuel, oil and waste only. The cost of attendance varies with the requirements and could not fairly be considered in a comparison of different kinds of power:

	Cost per swing average.	Number swings per year.
Kinnickinnic draw, 230 ft. D. T., wt. about 600 tons... No end lifts—*gasoline* engine power.	1.17c	5250
Milwaukee draw, 235 ft. D. T., wt. about 500 tons... No end lifts—*gas* engine power.	1.18c	16991
Winona draw, 360 ft. S. T., wt. about 600 tons... Toggle lifts—*gasoline* engine power.	2.29c	1759
North Branch draw at Deering, 176 ft. D. T., wt. about 400 tons... *Steam* engine power.	41.2c	278
Kinzie Street draw, 187 ft. D. T., wt. about 400 tons... *Electric* power.	1.5c	9000

Where the draw bridge swings frequently the cost of steam would be greatly reduced. Gasoline is particularly economical in the intermittant service that occurs with the usual draw bridge.

It must also be remembered that steam can be put in much less compass than gasoline, owing to the fact that steam engines are reversible, and a gasoline engine runs only one way, requiring special machinery for reversing purposes.

Mr. A. R. Eldridge: The C., B. & Q. Ry. Illinois river bridge (277 ft. single track) is operated by a 20 h. p. gasoline engine, and turns in two minutes, and the 368 ft. draw span over the St. Croix river is operated by a double 9 in. x 9 in. steam engine developing about 50 h. p. This latter bridge is turned very frequently and opens in about two minutes.

Mr. B. B. Carter: The selection of the prime mover or source of power for a draw span should conform to the importance of the span for both the railway service and of navigation, as related to the probable average number of swings or passing trains. Also to the length, weight and loading of the span, and the necessary speed of operation, as well as proximity to power supply. The writer has used steam, gasoline and electricity. On a span frequently operated, steam is quite economical, but also rather difficult of connection.

Gasoline is more economical on the average span and is almost the only thing for spans remote from settlements or sources of electric power, and especially when infrequently operated. It is also open to the same objection as steam for connections, with additional difficulties due to the engine not being reversible.

Electricity is almost ideal, and is as economical as any when the bridge location is within reasonable distance of an electric power current. It is very elastic in the application of the force and also in distribution of units. In driving end-lifts and rail-locks, separate motors can be used, with wires, the only connections necessary for the operation. No part of the bridge structure need be interfered with or pierced; distortions of the span do not affect the connections; and electric equalization is easy both for swinging and for end lift connections. The first cost is higher than any other arrangement, but on important spans this should not be considered. Electrical machinery as now made is as reliable as steam, and far more so than gasoline. The cost of maintenance is not higher than the other powers, and no troubles of coal, water, ashes or other impediments need be provided for. When traced to the source, the troubles in maintaining draw bridge machinery usually can be determined in faults of design. Often, however, they are due simply to carelessness in assembling or erecting.

The machinery, including all moving parts, is the most important part of a draw span, for this is what really makes it a draw span. Too often the cost is the first consideration, with efficiency and durability as secondary considerations.

Too much care cannot be given to the design, for simplicity, compactness and strength. The application of power should be as direct as possible without long shafting and especially bevel gearing. Bevel gearing is one of the worst mechanical details possible to apply in bridge work, owing to the necessity of accurate setting, rigid supporting, and its own inherent weakness.

Too much emphasis cannot be given to Mr. Reichmann's remarks concerning the inspection in shop and field by a competent mechanical man. It is the writer's experience that too often the machinery outfit is too weak in proportion to the mass of the bridge. The added cost to make the machinery much stronger is usually a small percentage of the total cost of the outfit; therefore, in his practice he leans towards the side of too much strength, but by so doing reduces the cost of repairs, delays and maintenance.

As a final remark, the writer would like to have a word with his friend, the civil engineer. Draw bridge machinery designing is about the most difficult problem that the mechanical engineer undertakes, and the civil engineer seems to have a chronic objection to doing anything to facilitate his work. The mechanical engineer must get around a thing by a set of bevel gears if he is to get around at all, otherwise he must go through, but be careful not to weaken the structure. The best results can be obtained only by hearty co-operation between the mechanical and the civil engineer, to the end that they overcome each other's difficulties. The writer is glad to say that in several of the bridges with which he has lately been connected, there has been thorough co-operation. If certain changes in the structure would make things better mechanically, without unduly weakening the structure or making it more expensive, these changes were made with the result that the entire bridge was greatly benefitted.

Mr. A. F. Robinson: It would be very interesting if, in addition to the data presented by Mr. Finley regarding cost per swing of fuel, etc., additional figures might be presented, covering the cost of labor under different conditions. This cost will vary in different localities, but the writer finds where there have been installed interlocking devices so that the span is operated by one man, that the saving in labor has been sufficient to more than pay interest on the cost of the entire installation of the interlocking plant.

The 300 ft. S. T. swing span over the Illinois river for the A., T. & St. F. Ry. is operated by a 24 h. p. gasoline engine, and is interlocked. This bridge is tended by only one man, and the results are entirely satisfactory. The writer might also add that the above Ry. Co. has what is known as the Taylor gasoline electric device—a small gasoline engine generating the electric current for all the signal lights.

The A., T. & St. F. Ry. Co. are now equipping three draw bridges on the "Valley Division" in California with power turning plants. These bridges are riveted throughout, and have what might be called jack-screw end-lifts. When the road was built these bridges were operated perhaps twice in twenty-four hours, and the railroad traffic was not unusaully heavy, so that the delay to trains and the cost of operating by hand was not a serious matter.

Last fall, however, the traffic had increased so that the records for the month of November showed something like seventeen hours of delay to trains of all kinds, at these draw bridges, and at once the matter was taken up of equipping these bridges with power.

The estimated first cost of power installation was a little in favor of gasoline as against electricity, and the estimated operating expense showed gasoline as being at least 25 per cent cheaper than electricity, from a local power company. Of course the authorities had to consider also the possible derangement of service where electricity is taken from a single power house over one wire. If the wire is down, all the current is gone for all three of the bridges, while with the gasoline plant one can hardly have more than one bridge out of service at one time.

As to the location of the engine houses, it seems to the writer that for a draw span of any length, especially where it is interlocked so that trains do not stop, you have no right to put the engine room down out of sight, at the level of the tracks. The proper place for the operator is overhead where he can see in all directions.

Mr. C. F. Loweth: The writer's experience covers the use of steam, gasoline and electric power for operating swing spans, and his present preference is for electric power wherever it can be economically obtained, and with reasonable assurance of freedom from interruption. Electric power is applied with much less complication of machinery than other kinds. In long spans the end lifts may be operated by small motors placed at the ends of the span, obviating a line of shafting the entire length of the bridge, with its connecting clutches and gearing at the center, all of which are otherwise required.

The new bridge of the C., M. & St. P. Ry. over the Mississippi river at Sabula is operated by electric power, and has electric interlocking signals: the current for both purposes is obtained from a gasoline power plant located on shore, and supplemented with storage batteries. Generally, however, the electricity supply is purchased from local electric light or street railway companies. As a general proposition the writer favors a power house at the track level.

5TH.—GENERAL QUESTIONS OF CONSTRUCTION.

Mr. W. H. Finley: Coming to the details of swing bridge design, that affect the question of maintenance, the writer is in thorough accord with Mr. Cartlidge as to the necessity for riveted connections wherever possible, particularly of the end floor beams. He also believes that the method of carrying the reaction of the span to the drum is worthy of consideration. The triangular tower shown in Fig. 5 is to be preferred to the frequently used rectangular tower. The writer believes that the triangular tower, with a short (hanging) link at the top, insures a better distribution of loads at the foot of the end posts (though the loads on the arms may be unequal) than the usual rectangular form.

A 300 ft. draw span built by the C., M. & St. P. Ry. is somewhat different from the ordinary draw span, in that the top chord is made discontinuous when the bridge is closed, thus securing positive reactions without the use of end lifts, as the arms are absolutely two single spans. The writer realizes that the method of accomplishing this by pulling down the center eye bars is not an economical one, but the bridge has been giving good satisfaction so far as the writer knows, though he has not seen this bridge for two years.

The writer would call attention to Fig. 6 as an example of a stiff riveted swing bridge. In this type of truss, not only are adjustable members avoided, but the uncertain eyebar is also eliminated.

Mr. A. F. Robinson: As to the design of the swing span itself, for some years the writer has been very much opposed to the idea of figuring a swing span as a continuous girder under live loading. When the Illinois river bridge was built the writer was anxious to design the structure as two independent fixed spans under live load, but the time was too short to undertake it. There should be no special difficulty in such a design. The end lifts can be made heavy enough to relieve the bars over the center of all dead and live load stress.

Mr. Schneider: The writer agrees with Mr. Cartlidge that there should be absolutely no adjustable members in the trusses of swing bridges, and that all parts subject to reversal of strain should be stiff members with riveted connections. This, in his opinion, applies to any truss; the ideal permanent structure should have no adjustable members.

Mr. F. C. Kunz (read by Mr. Belknap): The writer heartily endorses the author's recommendation, that truss-details should be all riveted except for eye bar members. In his designs, wherever possible, he even goes so far as to eliminate the use of eyebars entirely, making the whole truss one riveted body, instead of two separate ones connected over the center with eyebars.

Mr. C. F. Loweth: The writer believes in the use of riveted truss connections for draw spans, and his practice is generally to make the web and chord connections all riveted throughout, except the center top chords, and in large spans the largest tension web members.

The three hundred-foot span referred to by Mr. Finley, in which the arms are raised or lowered by drawing down the center top chord, thus making the span when closed absolutely two single spans, is giving good service, and doubtless will continue to, although the writer doubts if anyone will be strongly tempted to duplicate the design. It illustrates, however, the fact, that successful results in drawbridge practice need not follow stereotyped designs, providing the details are carefully worked out.

The Chicago, Milwaukee & St. Paul Railway has now in service four large counterbalanced swing bridges, and has under way three more. These are generally similar to the one illustrated by Fig. 20, which shows the double track bridge over the Menominee river in Milwaukee, the long arm being 143½ feet in length. Plans are now being made for a similar bridge to replace the bridge over the north branch of the Chicago river, near Kinzie street, in which the long arm will be 197 feet and the short arm 96 feet.

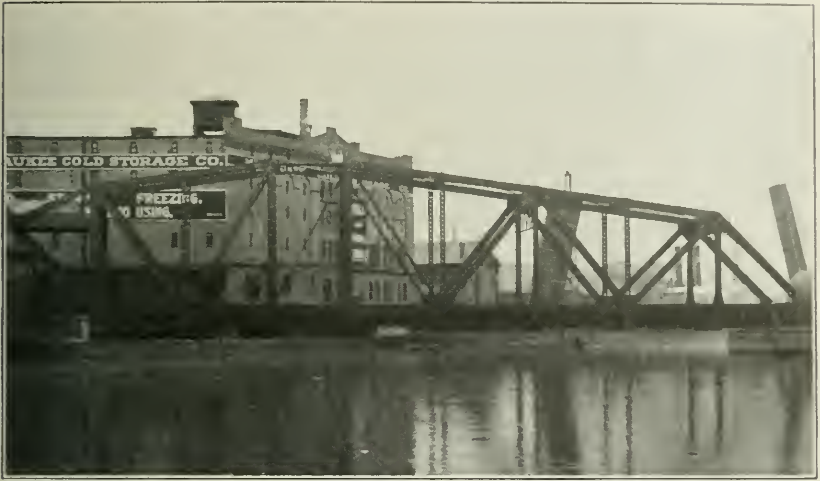


FIG 20—SWING SPAN, C. M. & ST. P. RY., MILWAUKEE. COUNTERBALANCE OVERHEAD AT LEFT-HAND END. BASCULE BRIDGE FOR CITY, BEYOND.

Mr. Andrews Allen: The writer is in entire accord with Mr. Cartlidge in regard to the importance of riveted members and connections in a draw span. Eye bars should only be used where they are large enough and have enough constant dead load strain to be perfectly stiff. The two arms may frequently be built to advantage as separate riveted spans, and then connected over the center by eye bars; the writer, however, does not see any particular use in making the two arms discontinuous under live load. The maximum stresses in the continuous bridge are not difficult to determine, and the amount of metal is not sensibly affected by figuring the bridge as a continuous girder. At the same time the additional machinery and power for making the arms discontinuous when closed must make a considerable addition to the cost of the machinery, and the cost of operation. The time of operation must also be largely increased, and so far as the writer can see there would be no resulting gain that could not be accomplished far more economically by the use of an end lift of sufficient power to prevent hammering.

As a corollary to the requirement of riveted joints and stiff members, the writer would also advocate the use of the Warren truss, which carries the stresses more directly, is generally more economical of metal, and requires less field riveting than the Pratt truss.

CLOSURE.

Mr. C. H. Cartlidge: The author cannot repress a feeling of gratification that the discussion of this paper has been so full and desires to express his thanks to those who have so ably taken part in the discussion. The value of any paper is greatly enhanced by discussion of this character.

In general, it may be said that the designs shown by the author have been commended, although in several points it appears from the discussion that better details have been devised.

It is sometimes the case that a designer has developed a certain set of details which is more or less distinctive and which there seems to be a tendency to uphold and defend to the exclusion of others. This is rather a hard statement and yet it is one which is worthy of consideration. It is evident that it should be the aim of every designer to sink his personal predilections and approach a problem of design with a mind open to good suggestions from every source.

The value of this paper and discussion, therefore, lies in the opportunity presented for making a selection from among several designs for the principal details. The writer has felt throughout that such details as were shown in the original paper are there for criticism, and that whether they be good or bad they would require no defense. At the same time it is a fact that it is not clear in all cases just what the operation of some of these details is, and certain of these misapprehensions will be mentioned and explained in closing.

In the matter of design of center, Mr. Schneider refers to the absence of means for adjusting the height between the pivot and truss. This is taken care of in the design shown, by means of large shim plates. These may be put in without any difficulty by jacking under the transom beams. Plates are provided for this purpose and shipped with the span.

One statement in Mr. Kunz's discussion, in which he refers to the uneven wear of the rollers, is not in accordance with the author's experience, inasmuch as each span moves through 90° and it is possible to so design the drum that it may be loaded on eight points. It is not difficult to so manage that each roller receives at some time the same load as any other. As a matter of fact the extended maintenance of several bridges of this character has developed no such difficulty with the rollers under the drum as is referred to, while the difficulty with a roller bearing center is not a matter of theory but of actual experience in several instances. The replacing of these rollers under the drum is a matter of no difficulty whatever as one or two rollers may be taken out without jacking the span or disturbing any part of the frame further than taking off the inner channel, the two channels being bolted together with turned bolts. In this connection the author wishes to corroborate the statement made by Mr. Strobel that in case cone bearings are used they should be rigidly held in stiff rings so connected as to prevent skewing of the cones.

Mr. Bainbridge's discussion of lubricants is particularly valuable.

In the matter of the end lift the most serious indictment which has been brought against the one shown, seems to be that it is not one which we would use under a fixed span, yet it is evident that a draw span does not require at its outer ends as rigid bearings as are needed for a fixed span. It is evident from the discussion that an end lift combining all the essentials has not yet been devised and it is hoped that a form will be devised which will combine the advantages of all those shown and mentioned in the paper and discussion.

Mr. Allen's discussion of the work of lifting by means of these single toggles as compared by the work done by wedges apparently neglects the greater frictional resistance offered by the wedges. The design which he has shown is however thoroughly efficient as it provides for centering the span and furnishes a flat bearing.

There seems to have been a misconception of the action of the rail lift shown and a decided difference of opinion as to the value of allowing the rail to drop after the span has been centered. When it is recalled that the span is centered by no form of end lift until the lifting has been completed, it becomes evident that the rail cannot fall exactly into place until then. The device shown which is, so far as the writer is aware, original with Mr. Morison, holds the rail in its highest position until the span has been lifted to full height and in exact position and then allows it to fall with enough of a shock to drive it into place without any difficulty. Frequent inspection of the working of this has not shown the necessity for sending a man to the end of the bridge to bring the rails to position. The preference on the part of several for the practice of fastening the rails to the lift, and pulling them back into position seems to the writer unwarranted. Lift rails if mitered, as they should be and so connected may and often do catch on the fixed rails and either cause a stoppage of the machinery or breakage of some part. The rails of all draw spans designed by the author are mitered as shown and no perceptible shock is occasioned by passing trains; the long miter providing very well for expansion.

It is possible that the sliding joint shown by several of those discussing the paper offers less chances for derailment than with lift rails, in spans not interlocked. It is fact, however, that unless the span be centered accurately no form of rail joint is of any value. It therefore follows that unless the span be interlocked with the rail operating mechanism in such a manner that the signals cannot be cleared until the rails are exactly in line no assurance of safety can be had. Further than this and most important of all, is the fact that absolute safety demands not only the interlocking of the span with the signals, but also the interlocking of the signals with a positive derailing device. Human frailty and liability to error render any other solution inadequate.

It is evident that if the draw span be protected by positive derails and these interlocked in such a manner that the track cannot be cleared until the span is centered and the rails dropped in line, absolute safety will be attained and trains may be run over the bridge at any desired speed. Such interlocking is possible with either design of rail lifts or joints advocated, and neither has any advantage of safety over the other without it.

CONCRETE PIPE CULVERTS.

O. P. CHAMBERLAIN, M. W. S. E.

Presented December 5, 1906.

The use of pipes for culverts, where comparatively small waterways are required through road or railroad embankments has, duing the past fifteen years, been steadily increasing. In modern railroad construction the use of pipes for small openings is almost universal. In reconstruction work on established railroad lines all wooden box culverts and many dry stone box culverts are gradually being replaced by pipe culverts. It is now regarded as the best engineering practice, for waterways, where areas of cross section may range from one to thirty-six square feet. to use pipes, either of cast iron, concrete or vitrified terra cotta, to carry small streams and surface drainage though road and and railroad embankments.

In the use of pipe culverts of varying construction, the type that has thus far given entire satisfaction has been that constructed of ordinary cast iron pressure pipes with bell and taper ends laid generally in twelve foot sections without caulking at the joints. This particular form of culvert commends itself to railroad engineers on account of its permanency, cheapness of maintenance and the ease with which it is installed. The use of such culverts, while economical in the long run, involves a heavy initial cost compared with the cost of wooden boxes and other types of small culverts. Recent experiments with concrete pipes have given rise to the hope that with them, satisfactory culverts may be constructed whose first cost will be but a fraction of the cost of iron pipe culverts and which at the same time can be as economically maintained as the last mentioned type. To invite discussion of the possibilities of concrete pipe culverts and to encourage broadening the field of experiment with this type of culvert is the purpose of this paper.

Both vitrified terra cotta and concrete pipes have been looked upon as failures by many of our railroad engineers. While, in this country, the use of concrete pipes for railroad culverts has been comparatively insignificant, there was a period when for several consecutive seasons many of the railroads put under their tracks so called "double thick" vitrified pipe culverts. This attempt to reduce the initial cost reacted forcibly on the maintenance of way way departments of these roads. Crushed and closed up vitrified pipe culverts increased the burdens of bridge supervisors road-masters and section men and were immediately responsible for many washouts. During the past few years the bridge departments of these roads have been assiduously employed in removing the broken remains and replacing them with cast iron pressure pipes, or in emergencies, with wooden boxes.

A form of concrete pipe of small diameter has long been used on the continent of Europe and more recently in America for small sewers and culverts. A longitudinal section of this forme of pipe showing the character of the joint is shown in Figure 1. For very small drain pipes, of from two to four inches inside diameter, they have stood fairly well. For larger diameters, particularly where subjected to varying vertical pressure, they have not been satisfactory. The weak joints are unable to withstand the vertical distortion consequent upon this varying pressure and fractures at, and adjacent to the joints, have destroyed the integrity of the sewers or culverts.

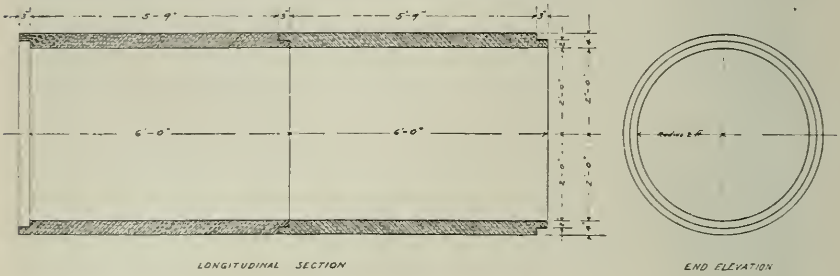
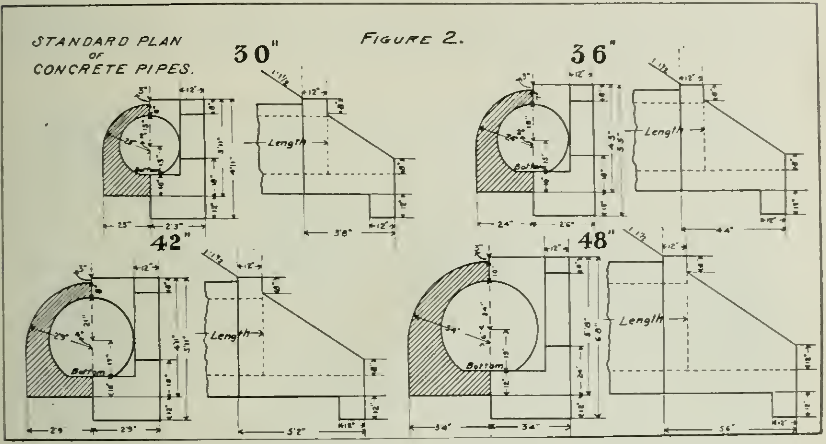


FIGURE 1

One of the principal claims of the pipe culvert for recognition, on economic grounds, is that it can be laid in the bed of the waterway on or near the natural surface of the bed of the stream without any foundation having been built for it. When laid in this manner, it is evident that, in ordinary soils, the culvert will, though laid to a uniform, straight grade line, ultimately be depressed more in the center of the embankment than at the sides and assume a grade line that is a vertical curve concave on its upper side. Any pipe laid as described above must meet this condition by having slight flexibility or play at the joints.

Within the past few years, amidst the great increase in the use of concrete in engineering construction and in the diversity of its uses, the attention, both of engineers and manufacturers has again been turned to the possibility of building satisfactory concrete pipe culverts, particularly for use in railroad embankments. Resulting from their efforts, two distinct forms of so called concrete pipe culverts have been produced: first, a continuous pipe, without joints, built through the embankment, the forms being laid in place and the work of putting in the concrete being conducted on the culvert site, the character of the work being similar to the construction of an ordinary concrete arch or sewer; second, a type of pipe which is built or moulded in sections at some central manufacturing plant, whence it may be transported to the culvert site, and placed in service by simply connecting the sections in place and filling in around the pipe, in the same manner that cast iron pipe is handled.

Figure 2 shows a copy of the working drawings for some culverts of the first type as built on one of the western railroad lines. In the opinion of the author it has no economic features to recommend it. The base is broadened to form a foundation and the culvert resembles a pipe only in that the cross section of the opening is approximately a circle. Its erection requires the same method of construction, involving the transportation of the raw materials to the culvert site, and the prosecution of the work by skilled mechanical labor, that is required in any arch culvert, while a semicircular arch culvert of the same sectional area would be in every way as substantial, and the forms for its erection, as well as the culvert itself, could be built and handled more cheaply than the type of culvert shown in Figure 2.



Without further consideration of this first type, let us discuss the second, which is, in fact as well as in name, a concrete pipe; manufactured at the factory, distributed and transported thence to the various sites where culverts are to be installed. In the author's opinion, assuming that it is feasible to build and install concrete pipes of the second type strong enough to resist the external pressure due to high embankments and heavy traffic, there are four essential conditions which must be successfully met, the first two involving the economical manufacture of the concrete pipes, and the third and fourth their permanency and integrity after their installation as culverts. They are as follows:

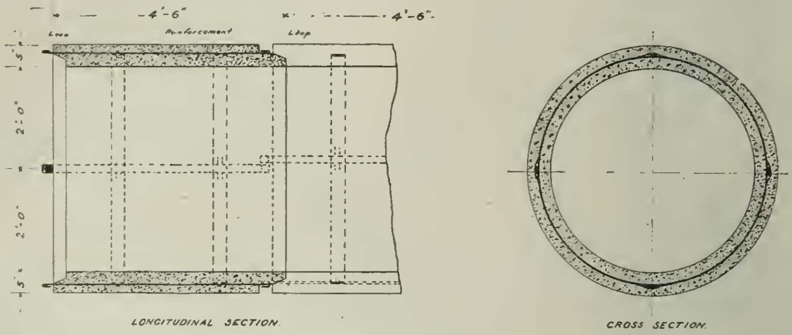
1. The concrete pipes for a considerable district should be manufactured at a central station or factory.

2. The concrete forms must be of such a character that the freshly mixed concrete can be run in from the top, each pipe being moulded or built in a vertical position, that is "on end."

3. The pipes must be so constructed as to allow some vertical displacement so that the culvert may assume a vertically curved grade line without fracture.

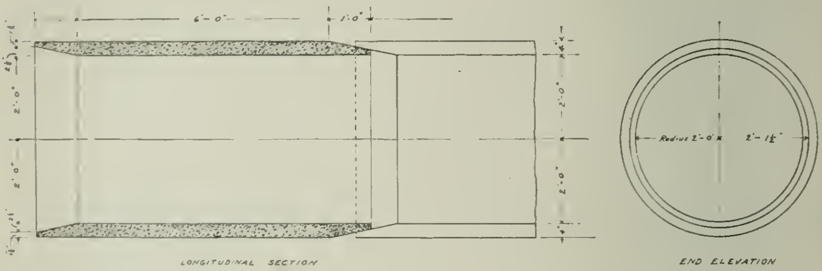
4. There must be some provision for expansion lengthwise of the culvert.

Figure 3 shows a pipe which is being manufactured and placed on the market as a commercial proposition by a company which is advocating the use of these pipes for sewers and culverts. It contains a reinforcement of four or five flat longitudinal iron or steel bars together with circular hoops which are built into the walls of the pipes. The longitudinal straps are hooked at each end. After the pipes are in place, end to end, the adjacent lengths are joined by running a joint hoop through these hooks at the ends of the bars of adjacent sections and then making up the joint to the same thickness as the rest of the culvert with cement mortar. There is no provision for either expansion or vertical displacement.



LONGITUDINAL SECTION. CROSS SECTION.

FIGURE 3



LONGITUDINAL SECTION END ELEVATION

FIGURE 4

One of the experimental culverts tried on one of our railroads was built substantially as shown in Figure 4. The outside of each length of pipe was tapered at one end and the opening correspondingly spread at the other. The pipes were installed by simply inserting the taper end of one length into the flared end of the adjoining length. The results of experiments with these culverts were not satisfactory, as the pipes failed by fracture at and near the joints during settlement, there being no provision for vertical displacement without fracture.

During the past summer the author built a number of culverts, using the very simplest form of pipe, a hollow cylinder whose bases are at right angles to its axis. A number of these pipes are shown in Figure 5 which is reproduced from a photograph taken at the site of manufacture. These pipes were built of an inside diameter of four feet and an outside diameter of five feet making the walls of the pipes six inches in thickness. These pipes, which resemble in shape the hollow clay tiles used for tile drains, have been placed in low embankments where their tops are but eighteen inches below the under sides of the cross ties. They were simply placed end to end in shallow ditches conforming with the outside surface of the pipes as nearly as it could be done by picks and shovels and the back and top filling of the earth embankment thoroughly tamped around and above the pipes. Thus far they have given satisfactory service under heavy freight traffic. They have not, however, been in use long enough to ensure their being an unqualified success.

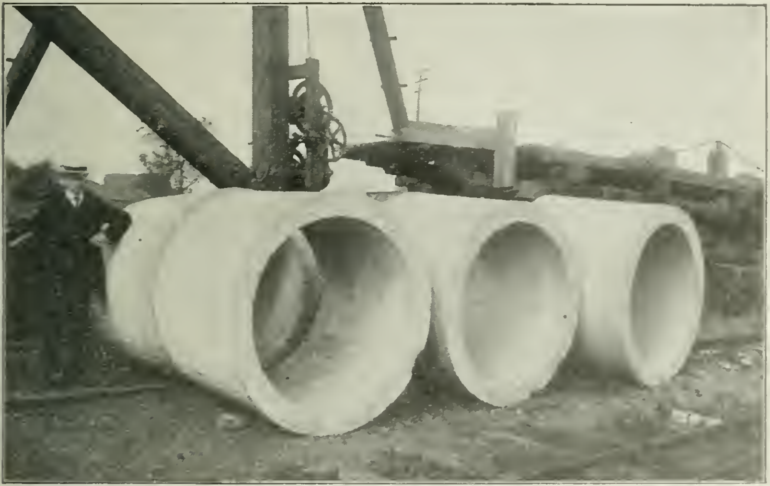


Fig. 5

Figure 6 is a reproduction of the working drawings from which the forms used in the construction of these pipes were built. Both forms are of wood, of ordinary wooden tank construction. The inner form has one wedge shaped loose stave which is withdrawn after the concrete has set for about twenty hours, thus collapsing the inner form and allowing it to be removed. The outer form is built in two pieces with heavy semicircular iron hoops on the outside, the hoops having loops at the ends. When the two sides of the outer form are in position, the loops on one side come into position just above the loops on the other side, and four steel pins are inserted in the loops to hold the two sides together while the form is being filled with concrete and while the concrete is setting. After the inner form has been removed, the two pins in the same vertical line are removed and the form opened horizontally on the hinges formed by the loops and pins on the opposite side. The inner and outer forms are then ready to be set up for building another pipe.

These pipes were built under a derrick and loaded by means of the derrick upon flat cars for transportation. At the culvert site they were unloaded and put in by an ordinary section gang with no appliances other than skids to remove the pipes from the cars.

As each four foot section of this pipe weighs about two tons, it was not deemed expedient to build sections of a greater length than four feet, to be unloaded and placed by hand. On a trunk line, however, where a derrick car is available for unloading and placing the pipes, there is no reason why they should not be built in six or eight foot sections.

The concrete used in manufacturing these pipes was composed of American Portland cement, limestone screenings and crushed limestone that had passed through a 3-4 inch diameter screen after everything that would pass through a 1-2 inch diameter screen had been removed. The concrete was mixed in the proportions of one part cement to three and one-half parts each of screenings and crushed stone. All work except the building of the forms was performed by common laborers. The cost of these pipes built under these conditions was $2.50 per lineal foot. This high price was due, in part, to the small scale on which the work was carried on, and amounts to $9.62 per cubic yard for the cost of the concrete. It should be possible to manufacture these pipes in quantities, using enough forms to keep one or two laborers steadily at work, for seven dollars per cubic yard, including the cost of forms. This is equivalent to $1.83 per lineal foot of four feet inside diameter concrete pipe. The cost of the lightest cast iron pipe of the same diameter is $9.75 per lineal foot.

The following table shows the comparative weights and cost of concrete and "Standard" cast iron pipes from one foot up to four feet in diameter; it is based on the above price of $7.00 per cubic yard for concrete and 1⅝ cents per pound for cast iron pipes.

TABLE SHOWING RELATIVE THICKNESS, WEIGHTS, AND COST OF "STANDARD" CAST IRON PIPE AND CONCRETE PIPE.

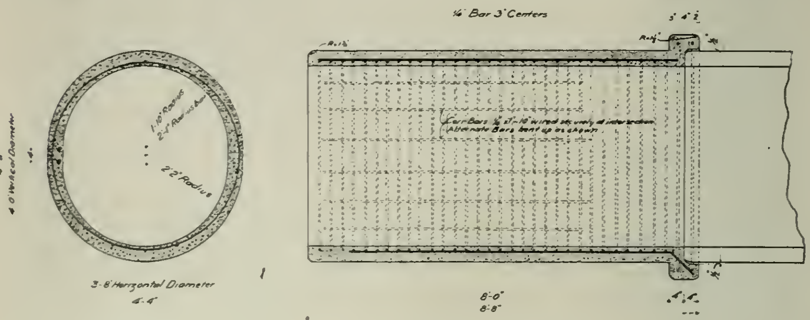
Size and kind of Pipe			Thickness in inches	Weight lbs. per lin. ft.	Cost per lin. ft.
12 in.	diam.	cast iron	0 33/64	75	$ 1.22
12 "	"	concrete	2	88	0.16
18 in.	"	cast iron	0 47/64	167	2.72
18 "	"	concrete	3	220	0.36
24 in.	"	cast iron	1	250	4.07
24 "	"	concrete	4 1/4	420	0.68
30 in.	"	cast iron	1 1/16	334	5.43
30 "	"	concrete	4 1/2	602	0.88
36 in.	"	cast iron	1 1/8	450	7.32
36 "	"	concrete	4 3/4	676	1.10
42 in.	"	cast iron	1 3/8	600	9.75
42 "	"	concrete	5 3/4	960	1.55
48 in.	"	cast iron	1 7/16	725	11.78
48 "	"	concrete	6	1131	1.83

In the above table the thickness for concrete pipes of various diameters have been taken as approximately proportional to the thickness of "Standard" cast iron pipes of the same diameter, the four feet diameter pipes being used as a basis for calculation.

The first cost of concrete pipes at the place of manufacture would, according to the above table, be less than one-sixth of the cost of cast iron pipes. The cost of transportation and of installing the pipes would, on account of the greater weight and greater number of pieces, probably be very nearly double for concrete pipes, what the same service would cost for cast iron pipes.

On account of the lack of reliable data regarding this cost the author is unable to give a fair comparative estimate of the cost of the two styles of culverts in place. However, since transportation and installation of iron pipes is but a small proportion of the cost of the completed culverts, it is evident that cost of a concrete pipe culvert in place would be but a small fraction of the cost of a cast iron pipe culvert of the same diameter, provided the pipes were hauled only moderate distances.

A type of concrete pipe which has, after considerable experimenting, been designed by Mr. C. H. Cartlidge of this Society and adopted by him for use on the C., B. & Q. Ry., is shown in Figure 7. This type of pipe has been made in sizes of two, three and four feet inside diameter. It has, in the opinion of Mr. Cartlidge, passed the experimental stage and is being used extensively on the C., B. & Q. Ry. This pipe is heavily reinforced by corrugated steel bars, the annular bars being so curved and placed as to be near the inside at the top and bottom of the culvert, and close to the outside on the sides of the pipe, so as to gain the greatest efficiency from the tensile strength of the reinforcing bars.


4'-0" Vertical Diameter
4'-8"
1'-10" Radius
2'-2" Radius
3'-8" Horizontal Diameter
4'-4"
¼" Bar 3" Centers
Corr. Bars ¼" x 7'-10" wired securely at intersection
Alternate Bars bent up as shown
8'-0"
8'-8"

CROSS SECTION

LONGITUDINAL SECTION.

FIGURE 7

The shape of these pipes is very nearly that of the ordinary cast iron pipes, the bell and taper ends being as nearly like those of the cast pressure pipes as the nature of the materials will admit. The provisions for expansion and vertical depression are ample.

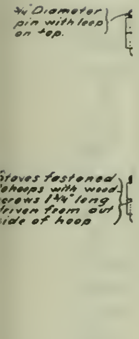
When we consider the expenditures made annually for pipes to be used as culverts, the importance of securing a satisfactory cheap substitute for cast iron pipes is of the highest importance, and while the author regards what has already been done in this line as experimental, the subject is one that cannot but be of interest to all bridge engineers and engineers of maintenance on our railroads.

In conclusion the author wishes to express his thanks to Mr. Cartlidge for the valuable plans and other data relative to the culverts designed by him for use on the C., B. & Q. Ry. furnished, for use in the preparation of this paper.

DISCUSSION.

Mr. C. H. Cartlidge: I have been much interested in Mr. Chamberlain's paper, first, because I am in the same business, myself, but particularly because we are working on somewhat parallel lines, yet slightly divergent; his pipe is plain concrete, while we are experimenting with reinforced concrete. I propose to make some comparisons between the relative economy of plain concrete and reinforced concrete, and the additional strength to be gained by reinforcing.

The C., B. & Q. pipe illustrated is 4 in. thick. The pipe designed by Mr. Chamberlain, and illustrated, is 6 in. thick. The


¾" Diameter pin with loop on top.
staves fastened to hoops with wood screws 1¼" long driven from outside of hoop
Two wedge shaped loose staves.
Semicircular templet of 2 layers 1½" boards nailed together with clinch nails before sawing to shape

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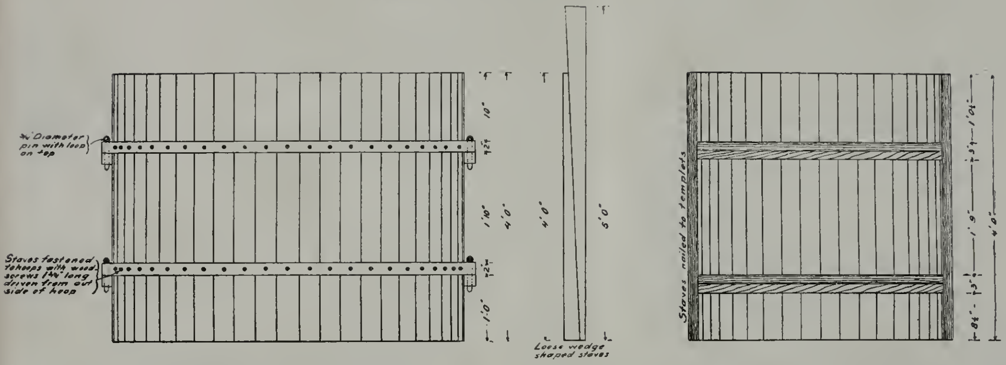
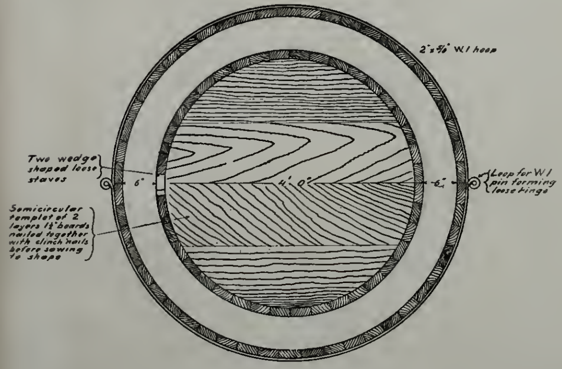

¾" Diameter pin with loop on top
Staves fastened to hoops with wood screws 1¾" long driven from out side of hoop
10"
2¼"
1'10"
2¼"
1'0"
4'0"
4'0"
5'0"
Loose wedge shaped staves
Staves nailed to templets
1'0½"
5½"
1'9"
3"
8½"
4'0"

ELEVATION OF OUTER FORM.

ELEVATION OF INNER FORM.


2" x 5/16" W.I hoop
Two wedge shaped loose staves
6"
4'0"
6"
Loop for W.I pin forming loose hinge
Semicircular templet of 2 layers 1½" boards nailed together with clinch nails before sawing to shape

C. & I. W. RR.

PLAN OF

FORMS FOR CONCRETE

PIPE CULVERT.

Scale 1" = 1ft. April 18th 1906.

HORIZONTAL SECTION.

FIGURE 6.

difference in cross section of the two pipes is approximately 2½ square feet. It is probable that that concrete can be built for less than twenty-five cents per ft.—perhaps twenty cents. This price is probably as low as can be obtained. There is in Mr. Chamberlain's pipe fifty cents worth per ft. more than in the C., B. & Q. pipe. There should be, to get the benefit of the concrete which is in that pipe, nearly 200 pounds in the length of a pipe, our lengths being 8 feet. That means that there should be, per ft. of pipe, about 25 pounds. I think that that steel can be put into concrete at not to exceed 3 cents per lb., making 75 cents per ft. of pipe. We have taken away 50 cents worth of concrete and added 75 cents worth of steel, faking an additional cost of 25 cents over what Mr. Chamberlain gives, if we can handle our concrete at the same price.

It is a very difficult matter to figure the strength of a concrete ring under an earth enbankment, for the fact that neither loads nor reactions are obtainable. We cannot make anything more than a guess at what they may be. But in figuring these as slabs the 4 in. reinforced concrete slabs should have about four times the strength of the 6 in. plain concrete slabs, so that, for an additional cost of, say, 25 cents per ft. we have gained three times the strength of the plain concrete pipe. Moreover, while it is quite necessary, in long lengths, to handle plain concrete pipe with a derrick, it is not necessary to handle reinforced concrete pipe in that way. This makes considerable saving.

What has just been said refers to the saving in material to be gained by the use of reinforcement. It is true that a reinforced pipe cannot be built as cheaply, in labor expense, as the plain pipe, but when the great increase in strength is considered it is money well spent. It is also true that the reinforced pipe effects an economy of from one-half to two-thirds the cost of iron pipe.

Mr. Chamberlain has set forth the comparative economy of concrete and cast iron pipe very thoroughly, but the saving in cost per ft. is not quite so easily grasped as the total saving in a particular case. For instance, on the C., B. & Q. Ry. there has been recommended for next years' work an amount of pipe which, in cast iron would cost about $40,000 more than concrete pipe.

Mr. A. J. Saxe, M. W. S. E. I would like to ask whether this reinforcing will be lasting? At a recent meeting of this society one of the questions discussed was the life of the iron inside of the concrete where it was subject to moisture; in the culvert it certainly is subject to moisture. Would that be a detriment in this case? That being the case, this reinforced pipe would not be as good as clear concrete pipe in a few years hence.

Mr. Cartlidge: In regard to the point brought out by Mr. Saxe —the corrosion of the iron in the pipe. I have taken steel bars out of the concrete which have been embedded for about twenty-two years, and they had the original scale on. These bars had been exposed to the water, but not as much as they would be in concrete pipes.

In regard to adhesion, I think it is quite likely that the salts that originally gripped the concrete may be dissolved, and the necessity for mechanical bond is much more apparent. That is true. Our practice has been to use only deformed bars.

Prof. A. N. Talbot, M. W. S. E. Perhaps a word or two may not be out of place on the subject of the loads which come upon concrete rings, or rings subject to earth pressure and the stresses developed in them. As was suggested by Mr. Cartlidge, it is quite difficult to determine the exact load, and the distribution of the load on a culvert in an earth embankment is uncertain. There is a wide variation in the way in which the earth filling is put on the pipe; also a great difference in the soil or material used. If the filling is done in such a way that it drops on the top of the pipe, falling to the side afterward and against the ends of the embankment already formed there, there may be an arch action, of course, which will relieve the pressure upon the culvert itself. If the material is sand, we may expect a horizontal pressure to act against the pipe which will greatly relieve the tensile stresses in the pipe. On the other hand, in the careless filling over such a pipe the filling may be done from one side only, and this may give a pressure on the pipe from an oblique direction, which is especially objectionable in case the pipe is reinforced merely against a vertical load. However the load may be distributed, it seems proper, in making our calculations, to consider the vertical load to be uniformly distributed horizontally over the pipe. I think it must be true also that there is a considerable horizontal pressure exerted against such pipe. I am more decidedly of this opinion now than formerly. My opinion has changed somewhat, and I believe that the pressure in the horizontal direction is considerable, although there is a possibility that the compression of the adjacent earth by this horizontal pressure may be diminished with the adjustment of the filling after continued wetting and drying out, and the new conditions may bring a release of this horizontal pressure to a certain extent.

If we know the distribution and amount of the load, both vertically and horizontally, we shall be able to tell fairly well what bending moment comes upon the pipe.

For a concentrated vertical load applied along the top element of the pipe and a similar support along the bottom element, the maximum bending moment is about one-sixth Wl, where W is the total load on the pipe and l the diameter at the middle of the thickness of the pipe. This maximum bending moment occurs at the extremities of both the horizontal and the vertical diameters, the tensile and compressive stresses in horizontal sections having a different position from that which they occupy in the vertical section. Between these sections the bending moment decreases and passes through zero near the 45° points. It will be seen that this maximum bending moment is somewhat less than that for a straight supported beam with load in the middle, which is ¼ Wl.

If we consider the load to be uniformly distributed over a horizontal plane and without horizontal pressure, the support below being of the same nature, the maximum bending moment may be taken to be one-sixteenth Wl and to be this amount at the extremities of the horizontal and vertical diameters. At the top of the pipe tension will come on the inner face and for the horizontal section it will be at the outer face. Of course, the compression caused by the vertical load will also have to be taken into consideration at the horizontal section, and it will act to reduce the tension at this section.

If, now, we consider that a horizontal pressure also exists and that this pressure is distributed uniformly over the vertical plane, the bending moments developed will be decreased, and for the loading under consideration the larger the horizontal pressure the smaller the bending moment becomes, reaching zero when the horizontal pressure equals the vertical pressure, a condition equivalent to uniformly distributed external pressure. At the same time the miximum compression due to the combined effect of bending action and compression will increase until at the limit cited it reaches the simple condition for a cylinder with uniformly distributed external load. If the horizontal pressure is one-fourth of the vertical pressure we may say that the maximum bending moment is three-fourths of that for vertical pressures alone, making it ¾ x one-sixteenth Wl = three sixty-fourths Wl. If it it is one-half of the vertical pressure, the maximum bending moment will be something like one-half of that for vertical pressures alone, making it 1-32 Wl. If, then, we knew the distribution of the pressures, the bending moment may be determined without difficulty. The moment of resistance of a section of a ring cannot be taken exactly as for a plain slab or straight section; the curvature brings some complications; but that can be gotten at, and the resisting moment determined.

When we come to consider the material for these rings and its condition, we have, in the case of the cast-iron pipe referred to, a great difference, or a large variation, in the thickness of the pipe in different parts of the circumference.

Pipe which may be obtained at the prices quoted in the paper is not first-class pipe as used in water-works construction; it is not generally even pipe that would be counted as seconds. A pipe was sent to me the other day for testing purposes—a 48 in. cast iron pipe—the thickness varied from ¾ in. in one place to 1¾ in. in another part of the circumference. This was in some respects a representative pipe. It got out of center in the making. It is plain to be seen that such pipe will not stand the load which we would naturally count on when the average thickness is taken from the weight of the pipe as it would be paid for. There is another difficulty with cast-iron pipe, in the effect of the hub upon the strength.

Coming to concrete pipe, we may make it of plain concrete or reinforce it. If made of plain concrete, it of course will stand the loads if made thick enough and if ordinarily good care is taken in its manufacture; but there is more need of care in the manufacture of the concrete, if the concrete is expected to take tension, than would be necessary if only compression is put upon the concrete. That is to say, some little fault in the manufacture of the pipe which would seriously affect its strength in resisting tension, will not have the same effect on the compression side.

A difficulty with concrete pipe is that it must be handled carefully while being put in place and until the filling is placed over it. Another difficulty is that, when this pipe breaks, it breaks as cast-iron pipe would in such a way that it will utterly fail unless it is held by strong lateral pressure, and that failure will be without the warning given in case the pipe is reinforced. A concrete beam breaks without much deflection and breaks suddenly, while a reinforced concrete beam will deflect considerably after it has passed its proper load, providing, of course, it is not over-reinforced.

The form of pipe which was illustrated by lantern slide views, and which contains a reinforcement placed as bands at the middle of the thickness of the pipe close to the neutral axis, has for its principal advantage over plain concrete pipe the two things mentioned,—that it may be handled more roughly than ordinary concrete pipe, and that when it is loaded, it will deflect much more before final failure than plain concrete pipe. If concrete pipe is to be reinforced, however, the steel should be placed where it will take the tension, at the lower side at the top section and at the outer side at the ends of the horizontal diameters. It is not necessary, of course, to make a complete circle of reinforcement. It may be more satisfactory to do it in that way, although it would serve the purpose to carry it from the positions of maximum bending moments a short distance on either side, leaving the portion near the 45° points where the bending moment is little, or not large, either without reinforcement or with a small amount.

While on this point of reinforcement, let me suggest that the pipe described tonight, used by the C., B. & Q. Ry., may have its strength materially increased by merely thickening it, say, 1 in. at the top or bottom where the maximum bending moment comes. This can be done on the outside, or even on the inside for a short distance, without much decreasing the waterway. You will understand that the steel is to be kept at the same distance from the face of the concrete as in the original pipe. To show the advantage of this you will note that the moment arm of the couple formed by the tension in the steel and the compression in the concrete is some portion of the distance from the center of the steel to the compression face—say 85 per cent. That in the pipe described was something less than 3 in. If the intervals could be made 1 in. more, we should have this amount arm 4 in., and the resisting moment of the pipe would be increased in this proportion. In addition to the stresses due to flexure, there is, of course, a compression distributed across the pipe which increases the compressive stress on one side of this beam, and decreases the tensile stress, just as in a long column after the compressive stress is calculated, it is added to the stress on the compression side and subtracted from that on the tension side.

In the paper reference was made to the expansion of the pipe. I suppose the allowance for expansion and the arrangement for taking it will depend largely upon the location. There is an interesting experiment going on at St. Joseph, Missouri, where last winter there was put in several hundred feet of lines of sewer, built with the kind of pipe described here,—the Jackson Sewer Pipe Company's pipe. This was laid in the winter, joints were made as described, and left exposed. The sewer was laid on pile and timber foundation in a part of the Missouri river, which was to be filled in. The terminal company did this work in order to reclaim quite a stretch of land along the river. There were perhaps five or six lines of these sewers, ranging from four to six feet in diameter, and perhaps three hundred to four hundred feet long. Mr. S. W. Fox, the engineer having charge of the work, made arrangements to measure the length of this pipe to see what the effect of change of temperature would be through the winter and summer. At that time he was quite certain that the filling would all be done before summer came, but the work had not been completed last summer, and I understand no change was found in the length of pipe. Of course we have a somewhat different condition in the case of sewers, in that the water flowing through is at a nearly constant temperature, and the pipe itself is not as cold as it would be otherwise. But it leads one to wonder how much of an allowance is necessary in the case of pipe under embankments, especially if the pipe is put in during moderate weather. If the pipes were laid in sections, as would be the case if they were transported, there would seemingly be enough space left between the ends of the pipe to allow for expansion.

The question of the hub and of the connection between pipes seems to me a very important one. You noticed in one view that the concrete pipe was ring pipe without other point connection. The pipe made by the C., B. & O. Ry. has a strong and well made hub. I wonder what is the advantage in that hub. There is certainly a disadvantage. You remember that the bending amount when the load is concentrated along an element of the pipe is 1-16 Wl, while for a load uniformly distributed horizontally it is 1-16 Wl, the former being over 2½ times as much as the latter.

It seems to me that with only ordinary care in laying and with the chances for settlement and with the greater strength of the hub, a considerable part of the weight on the pipe may rest upon the hub at a single point rather than be distributed, and that we may in this way lose some of the advantages which would certainly come with the uniform embedding of the pipe around its circumference. Possibly it would be well to use some form of joint similar to the ring joint formerly used in vitrified sewers. Take segments of a ring of the necessary width and of convenient length, say six to the circle, and put a mortar joint around for the full circumference. This would have a further advantage from the fact that the settlement of one end of a pipe would not affect the adjoining pipe, and no harm would be done. Possibly even such a joint as this would not be necessary. It seems to me, in the same connection, that the break in cast iron pipe must be frequently due to the fact that one end of the pipe rests on the bell, and insead of having a uniform bearing we have a support at a single point.

Last year there were made, at the University of Illinois, some tests on plain concrete rings. These tests were conducted by Mr. W. A. Slater to test the accuracy of an analysis of the stresses and resisting moments in such rings. The first break appeared at top and bottom of the pipe. If the test was continued long enough there would be a break at the sides. In order to get a definite loading in these tests the load was applied on a line or element at the top, and the pipe rested on a line at the bottom. These concrete rings were two feet long and 24 in. and 48 in. in diameter. The rings 48 in. in diameter were 10 in. thick and 6 in. thick while those 24 in. in diameter were 3 in. and 5 in. thick. I remember that the average load for the 48 in. ring, 10 in. thick, was about 6,000 pounds per lineal foot, or 12,000 pounds for the whole piece. That, as I figure it, would give, if the same concrete were used, for the 48 in. pipe, 6 in. thick, something like 2,000 pounds per foot for concentrated load, and perhaps something like 5,000 pounds per foot for a uniformly distributed load and no horizontal support. The strength of the reinforced concrete pipe described by Mr. Cartlidge, with the additional reinforcement he mentions, would be as much as two or three times as great.

Recently we put a load upon one of these 48 in. pipes (C., B. & Q.) up to the limit of the capacity of our loading apparatus, 101,000 lbs., without causing failure. This pipe was as described—48 in. internal diameter, 4 in. thick, 8 ft. long, plus the length of the hub. The pipe was laid in a sand bed with 12 in. of sand below it, and 9 in. of sand on either side next to the box. This sand was thrown in and wet down with water and the filling continued in this way to the top of the pipe. A saddle was placed over the pipe, arranged so that there were 12 in. of vertical depth of sand between any element of the pipe and the timber which formed the saddle. The pressure applied by levers from a testing machine was distributed along this saddle. Under these conditions, with a load of 70 000 pounds, minute cracks appeared at points above and below, the same as appear when concrete is stretched to a certain amount on the tension side in reinforced concrete beams. These cracks became more numerous as the load was increased and grew slightly larger, but at no time were they larger than the ordinary fine cracks found in testing concrete beams. We could not examine the outside of the pipe at the sides, but after the sand was removed an examination failed to disclose any cracks. If cracks had appeared here they had closed up so completely as not to be found. The cracks at top and bottom were visible after the load was released, but they had closed up considerably. The horizontal diameter increased and the vertical diameter decreased something like ¼ in. with this test load. I will say that the calculations made for the load which would cause failure in this reinforced pipe proved not only that the load was well distributed horizontally, but also that there must have been considerable horizontal pressure supporting the pipe laterally, for without lateral support (horizontal pressure from sand) the calculated strength of the pipe is something like 65,000 pounds. We have here a bending moment which must have been not more than two-thirds of that calculated for no horizontal support, and it seems quite evident that the pipe would have stood twice the 65,000 pounds.

We are expecting to construct another device for testing and finally to break this pipe, and we hope to get information which will be of interest.

One feature of this test may be worthy of note. The sand placed under the pipe and that above the pipe compressed very little. The sand below and above pressed down less than ½ in. under the load of 101,000 pounds. This would indicate that the lateral pressure of the sand from the box is much more than would ordinarily be considered to be the case. If we are to judge from this, the lateral pressure against culvert pipes in an embankment, if properly imbedded and properly filled in, will be considerable and adds much to the stability of the structure. I am convinced that a little more care used in filling in around the culvert would be money well expended.

To show the effect of lateral pressure upon the stresses brought upon a pipe, the experience with a cast iron pipe may be cited. In the test of a 48-in. cast iron pipe 6 ft. long, imbedded in sand in the manner described for the test of the reinforced concrete pipe, after applying a load of 100,000 pounds in the usual way, the rods connecting the sides of the box were loosened so that little lateral or horizontal pressure came upon the pipe, though the manner of distribution of the vertical load remained the same, and a load of 100,000 pounds was again applied. With the rods tight (sand held laterally by the sides of the box), the change in the horizontal and in the vertical diameter at the spigot end was about

0.37 inch. With the rods loose (little lateral support for the sand), the change in these diameters was 1.24 inch. The deformations were 3 1-3 times as much, and the stresses developed in the pipe were probably about in the same ratio, that is, the stresses with the rods loose were 3 1-3 times as much as when tight. For lower loads similar ratio between changes was observed.

Mr. Chamberlain: I desire to say something in regard to the comparison which Mr. Cartlidge made between the cost of producing a reinforced pipe and the cost of producing a plain concrete pipe. I think that the figures given are not entirely fair, from the fact that it requires a different class of labor to handle a reinforced concrete construction from that which is required for handling ordinary concrete. I regard Mr. Cartlidge's reinforced pipe a very excellent one, but it requires a certain amount of mechanical skill to place the reinforcement in the forms properly, and it is more difficult to put the concrete in a form where reinforcement is used than in plain concrete; consequently the comparative cost of labor is hardly a fair one.

I was very glad that Prof. Talbot brought up the point in regard to the bell and spigot end of concrete pipe. He brought out very clearly the fact that pipe failures are often due, in a great measure, to the pressure upon the bell end of the pipe; that is, the concentrated load on the bell end (he said in cast iron pipe); and it was for that reason that I made this attempt in the use of pipe without any bell and nozzle joint. The bed in which the pipe is laid is very nearly uniform; that is, the bed would not vary to any great extent within reasonable limits. The first culvert I put in, after being in for some three or four months, had a variation in the joints fitting vertically, in the alignment of only ¾ in., and yet it was laid in a soft top soil. The earth for the trench was simply taken out with a shovel. The back filling was very carefully done. The work was all done by section laborers: at the same time I know that the back filling was carefully put in.

Mr. Abbott: Why could not planks be laid down for this pipe to be laid on, thus insuring an alignment?

Mr. Chamberlain: The foreman suggested that to me, but I thought it would not be a good idea, from the fact that it would put an excess pressure on the outside of the pipe where it bears upon the plank, and the external pressure would not be distributed along the outside surface of the pipe. I think that point is well taken. Even if it is laid in soft soil it will form a vertical curve ultimately under the pressure of the embankment and weight of the train. I think the proper way to put them in is to make some allowance for settlement.

In regard to the bell joint. One point has not been brought out: that the bell and nozzle end used in cast iron pipe is a joint designed originally to make a tight joint for water pipes, to resist the internal pressure and not designed for the conditions which obtain in a sewer or culvert. It seems to me, if we are going to put a lap joint of any kind there at all, an arrangement such as Prof. Talbot suggests would be more satisfactory and less liable to damage the pipe and cause failure.

There is another thing that appeals to me in the same connection, and that is, the pipe could be much more cheaply constructed. The reinforcing and building of the bell end requires considerable elaboration in the forms, etc.

One point that Prof. Talbot made is one which we all agree is a very good one; that is, the possibility of strengthening a culvert or pipe by increasing the vertical section at top and bottom.

ADDENDA

APPLICATION OF REINFORCED CONCRETE TO CIRCULAR SEWERS.

Mr. C. H. Tutton (By Letter).

The following is written with the hope of inducing some uniformity in the application of metal reinforcement to circular sewers, which now appears to be largely guided by chance, and although the method here pursued is open to criticism, it is believed to be safe.

A.—*Thickness of Concrete.*

Assume the sewer to have a diameter of D inches, and to be built at the depth x feet below the surface of the ground as measured to the center of the sewer. Further, suppose the covering material to weigh 108 lbs. per cubic foot. The nature of a sewer trench and back fill in same differs from that from a fill over an arch, so that for all practical purposes the vertical pressure may be taken as uniformly distributed over the sewer at $\frac{108Dx}{144}=\frac{3}{4}Dx$ pounds per lineal inch. This would give $\frac{3}{8}Dx$ pounds pressure upon each springing, and a horizontal component of thrust at the crown of $\frac{3}{16}Dx$ pounds per lineal inch.

Assuming these stresses to be wholly compressive and resisted entirely by the concrete, and also allowing the resistance of the concrete to be 250 pounds per square inch, the neat thickness T of the concrete in inches will be given by $\frac{3Dx}{8T}=250$; whence

$$T=.0015Dx. \qquad (1)$$

The same result is obtained by considering this load to act as a "hoop compression," the load being $\frac{3}{4}x$ pounds per square inch.

Construction considerations will require this to be increased for small sewers of neat concrete, as well as in larger ones, when it must be increased for the purpose of imbedding the metal reinforcement.

B.—*Amount of Metal.*

Assume that a bursting pressue of p pounds per square inch may exist from internal sources, subject to the ordinary rules of hoop tension, and to be guarded against wholly by the metal reinforcement.

For this purpose it is proposed to place a spiral hoop around the sewer whose pitch shall be m inches, and also to introduce n longitudinal rods or bars, which, consequently, will be at the distance $\frac{\pi D}{n}$ apart. Let s be the allowable stress per square inch in the hoop, and f that in the longitudinal.

Then for the hoop tension t, over the length m, which is the pitch of the spiral, $t = \frac{pDm}{2}$ from which

Area of hoop. any shape $\qquad a = \frac{pm}{2s} D \qquad$ (2)

Diameter of hoop. if round $\qquad \Delta = \sqrt{\frac{2pm}{\pi s} D} \qquad$ (3)

Each longitudinal (when properly wired) may be considered as a beam fixed at each crossing of the hoop, hence will have a span length of m inches and width between longitudinals of $\frac{\pi D}{n}$ inches. The load will therefore be $W = \frac{\pi D}{n} m. p.$ giving in the formula for fixed ends the bending moment $M = \frac{WL}{12} = \frac{\pi D m p}{n} \frac{m}{12} = \frac{\pi p m^2}{12n} D$ The resisting moment of the beam is $\frac{fI}{y}$ whose value is, for bars of width b and depth h, $\frac{bh^2 f}{6}$; for round rods of diameter d, this becomes $\frac{\pi d^3 f}{32}$

Equaling these respectively with the value of M just found for

Longitudinal bars $\qquad bh^2 = \frac{\pi p m^2}{2fn} D \qquad$ (4)

Longitudinal rods $\qquad d = \sqrt[3]{\frac{8pm^2}{3fn} D} \qquad$ (5)

C.—*Practical Values.*

It will generally be found to be good practice to take $n = \frac{D}{4}$ which will make the longitudinals 4π, or about 12½ inches apart. It is generally considered that the pitch of the spiral should be from 1-7 to 1-10 of the diameter hooped, but here it will be taken equal to the distance between the rods, or 4π inches. Making these substitutions; that is,

$$n = \frac{D}{4}, \text{ and } m = 4\pi, \text{ in (2) to (5) they become}$$

$$a = \frac{2\pi pD}{s}; \quad \Delta = \sqrt{\frac{8pD}{s}}; \quad bh^2 = \frac{32\pi^3 p}{f}; \quad d = \sqrt[3]{\frac{512\pi^2 p}{f}}$$

Next, assuming $s = f = 1600$ lbs., the following simple forms obtain:

$$a = .0003927pD; \quad \Delta = .02236\sqrt{pD}; \quad bh^2 = .062p; \quad d = .681\sqrt[3]{p}$$

D.—*Example.*

Take a 72 inch sewer and let $x = 40$ feet. Then $T = 4.32$in. neat. For values of p of 10, 20 and 30 pounds per square inch, which correspond to water pressures of 23, 46 and 69 feet respectively:

		$p = 10$	$p = 20$	$p = 30$
For hoop area	a in. s6. in.	.282	.564	.846
If a bar		3-16x1½in.	⅜x1½ in.	9-16x1½ in.
If round		⅝ in. dia.	⅞ in. dia.	1 1-16 in. dia.
Longitudinal	if square	⅞ in.	1⅛ in.	1¼ in.
If bars		⅝x1 in.	9-16x1½ in.	⅝x1¾ in.
If round		1 in. dia.	1¼ in. dia.	1½ in. dia.

The sewer thickness of 4.32 in. must now be increased to imbed the particular set of bars or rods chosen. Values for $p = 10$ are probably as high as the average sewer will call for.

E.—*Remarks.*

No attempt is made in the preceding to make these materials act together as in a beam, since it cannot be predicted whether the pressure will be wholly external as in dry weather flow in a storm system, or partially internal as in flood surcharge.

It is suggested that the metal should vary in position as it encircles the sewer, that it may act in tension to support the concrete at the points of rupture known to exist in an arch, under the supposition that the load is wholly external. The longitudinals should be carefully wired to the hoops at each crossing to realize the condition of a fixed beam.

In general it should be remembered that sticking in the rods, bars and hoops, hit and miss, does not constitute reinforced concrete.

For sewer purposes a 1:2:4 mixture is recommended.

Finally: Equations 1 to 5 are given in general shape, and should any other constants than these here given be desired for use, they can easily be substituted in these formulæ.

It is also quite possible that on account of reduced distance, forms of wire cloth, expanded metal, etc., could be chosen to fulfil all necessary conditions, but to make anything like an intelligent choice more data would have to be known than the manufacturers at present seem willing to give.

The theory can also be applied to water pipes and force mains by increasing the value of p.

TESTS OF BOND BETWEEN CONCRETE AND STEEL.

T. L. Condron, M. W. S. E.

Presented December 5, 1906.

The results of tests that have been reported on the strength of bond or adhesion between concrete and steel for plain, round and square bars are remarkable because of the lack of uniformity and wide variation, and indicate that there are so many conditions effecting this value even in laboratory experiments that engineers may well question if any dependence at all can be placed upon the adhesion of plain bars to concrete. The writer has studied all the results of bond or adhesion tests that have come to his attention. He finds from these reports that the strength of bond or adhesion obtained for plain bars embedded in Portland cement mortar and Portland cement concrete ranges from less than 100 lbs. to over 800 lbs. per square inch of embedded surface of plain bars.

The reports studied by the writer include the following, the figures accompanying the names indicating the minimum and maximum results reported in each case in pounds per square inch of embedded surface of plain round and square bars:

Zeitschrift des Vereins Deutcher Ingenieure (Vol. 49, '05) Cement Age, Oct., 1905	83 to 592
E. Morsh (From Beton und Eisen, 1903)	100 to 696
E. S. Wheeler, U. S. Assistant Engineer	111 to 556
Prof. A. N. Talbot, University of Illinois	174 to 386
Prof. C. E. DePuy, Lewis Institute	188 to 341
Prof. C. W. Spofford, Mass. Institute of Technology	219 to 374
S. W. Emerson, Case School of Applied Science	278 to 587
Prof. F. H. Constant, University of Minnesota	316 to 854
Prof. W. K. Hatt, Purdue University	470 to 756
Prof. Bauschinger (From Buel & Hill)	570 to 640

This strength of bond or adhesion depends upon the following factors; any or all of which may vary: Quality of cement; character of sand or stone dust used in the mortar; ratio of cement to sand or stone dust; sizes of gravel or broken stone used in concrete; ratio of mortar to gravel or broken stone; degree of placticity or percentage of water used in mixing mortar and concrete; thoroughness of mixing process; care with which mortar or concrete is placed; amount of leakage of mortar from concrete because of defective forms; possible disturbance of concrete during time of setting, breaking the initial adhesion to bars (this may easily result from tamping on or near concrete that has taken its initial set); the condition of the surface of the bars; and the age of the concrete.

M. Breuille reports in the Annals des Ponts et Chaussees, 1902, the results of tests made to ascertain the action of water and moisture on reinforced concrete. He reports that by soaking in water for nine months the adhesion between iron and concrete is reduced from one-half to two-thirds, and in time the adhesion is entirely destroyed. This is of vast importance in connection with tunnel, foundation and bridge or culvert work.

It is evident that some positive mechanical bond between steel bars and concrete must be used in reinforced concrete structures to insure their permanence and reliability. In order to investigate the relative strength of bond developed by different forms of bars in the same kind of concrete and under otherwise identical conditions, the writer arranged with C. E. DePuy, Professor of Mechanical Engineering in Lewis Institute, Chicago to make a series of bond tests, in which not only the stresses necessary to pull out the bars would be recorded but also the amount the bars moved or slipped under increments of stress would be recorded. He submits herewith, as an appendix, Prof. Depuy's report of these tests. In doing so, the writer desires to call attention to the fact that so far as he is aware these are the first tests, the results of which have been published, in which any record of the amount of the slip of bars as well as the stresses on the bars have been recorded.

From the results, as reported by Prof. DePuy, the writer has prepared, four diagrams showing graphically (1) the relative resistance to movement or slip, and (2) the relative efficiency of the seven different kinds of bars when subjected to stress.

Plates I and II show the relative resistances of the bars when embedded 16 inches and 24 inches. These two plates are the same as the third and fifth sections of Fig. 2 of Prof. DePuy's report but show the curves extended to include ¼ inch slip.

Plates III and IV show the relative efficiencies of the bars when embedded 16 inches and 24 inches. On each of these two plates the highest result obtained with a slip of not more than 1-100 inch is taken as 100%. The solid black spaces show the loads applied to the bars without causing any slip, and the open spaces, the loads causing slips of 1/100 inch.

In the writer's opinion the ideal shape of a reinforcing bar is one that will enable the full elastic limit of the steel to be developed by a short embedment without any appreciable slip. As to the length of embedment we find here that with embedments equal to 26 diameters, the corrugated bars developed 50,000 lbs. with 1/200 inch slip, while the same length of embedment developed but 16,000 lbs. in the plain, 25,000 lbs. in the twisted and 36,000 lbs. in the Thacher bars.

A series of tests were made at the U. S. Testing Laboratory at the Watertown Arsenal recently to determine the "adhesion resistance of steel bars in cement and mortar prisms." In these tests both twisted and corrugated bars were tested. In the report it is stated,

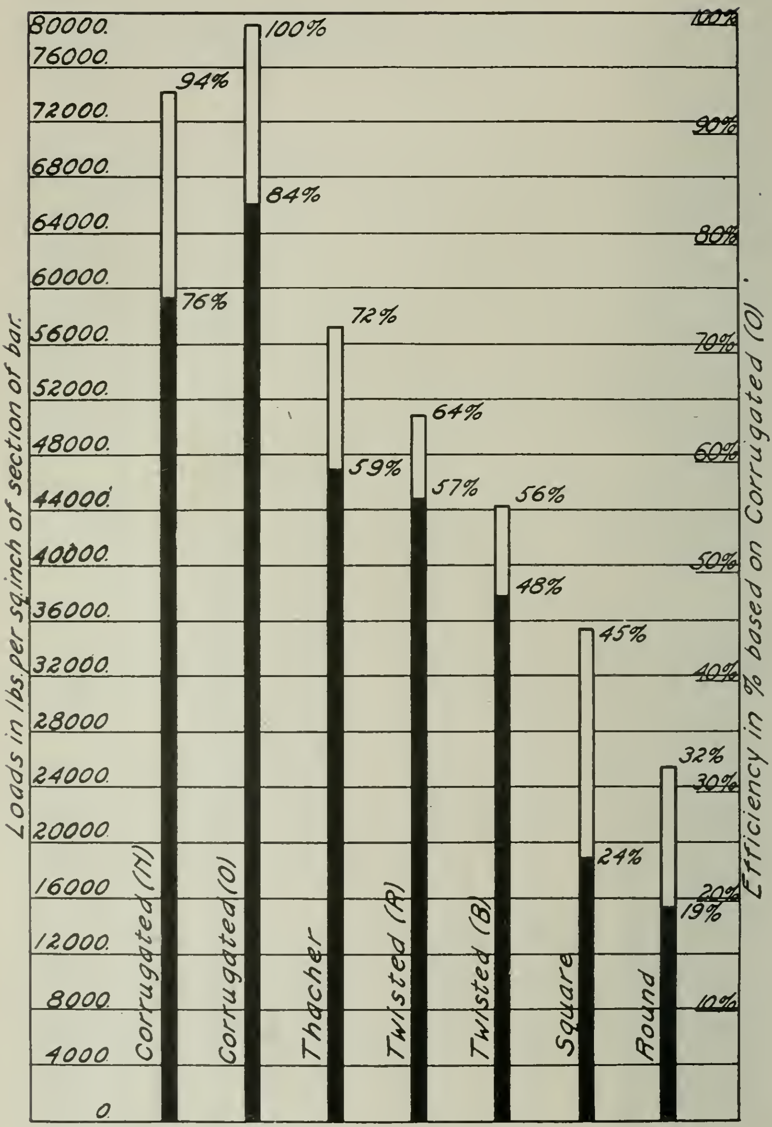


PLATE I. MOVEMENT OF BARS EMBEDDED 16 INCHES.

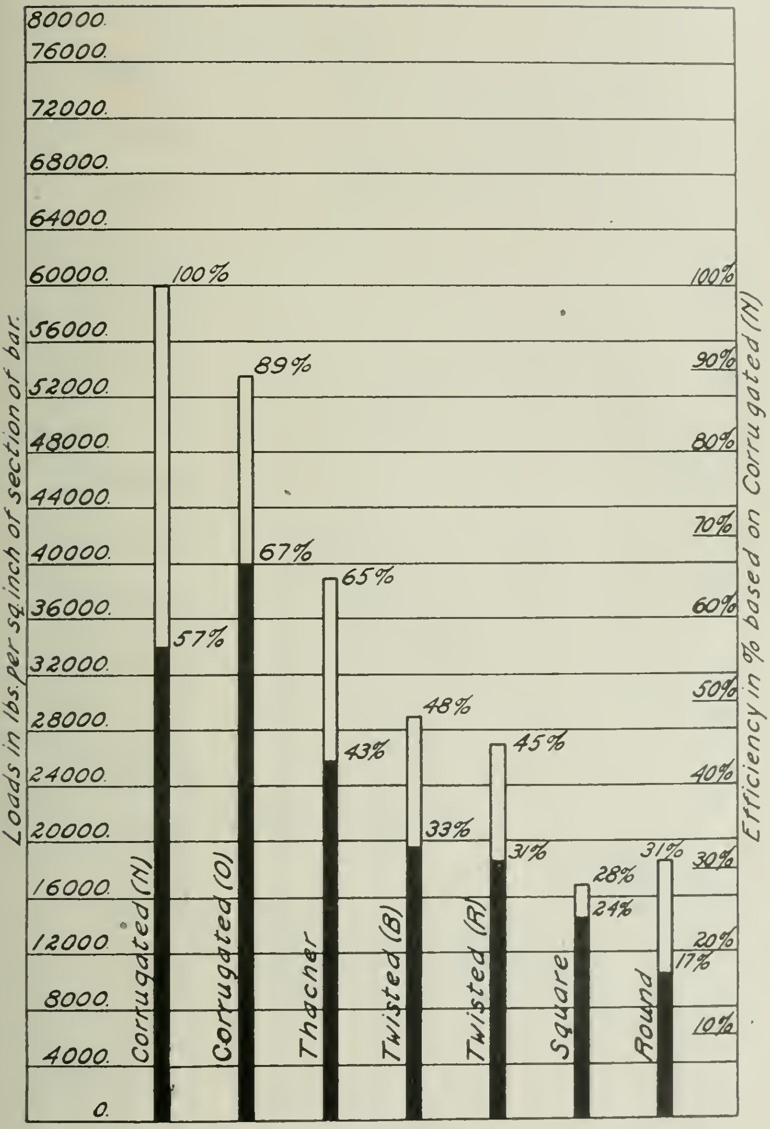


PLATE II. MOVEMENT OF BARS EMBEDDED 24 INCHES.

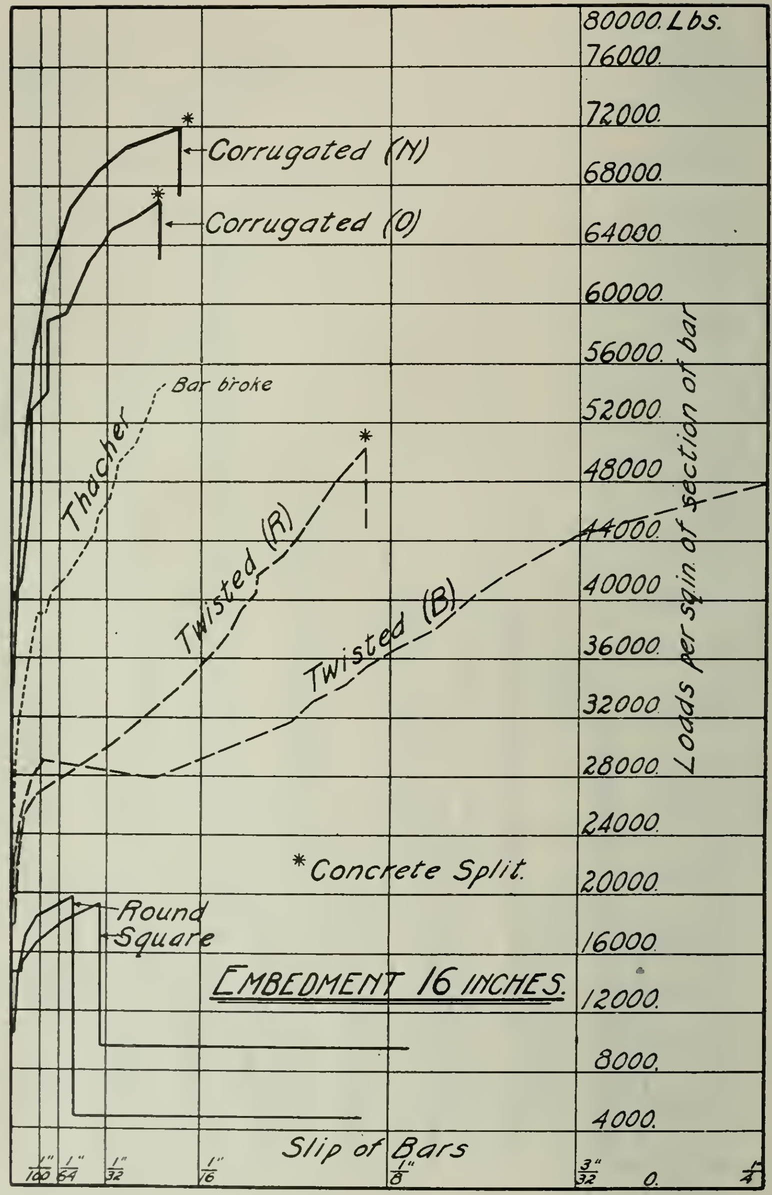


PLATE III. RELATIVE EFFICIENCIES OF BARS EMBEDDED 16 INCHES.

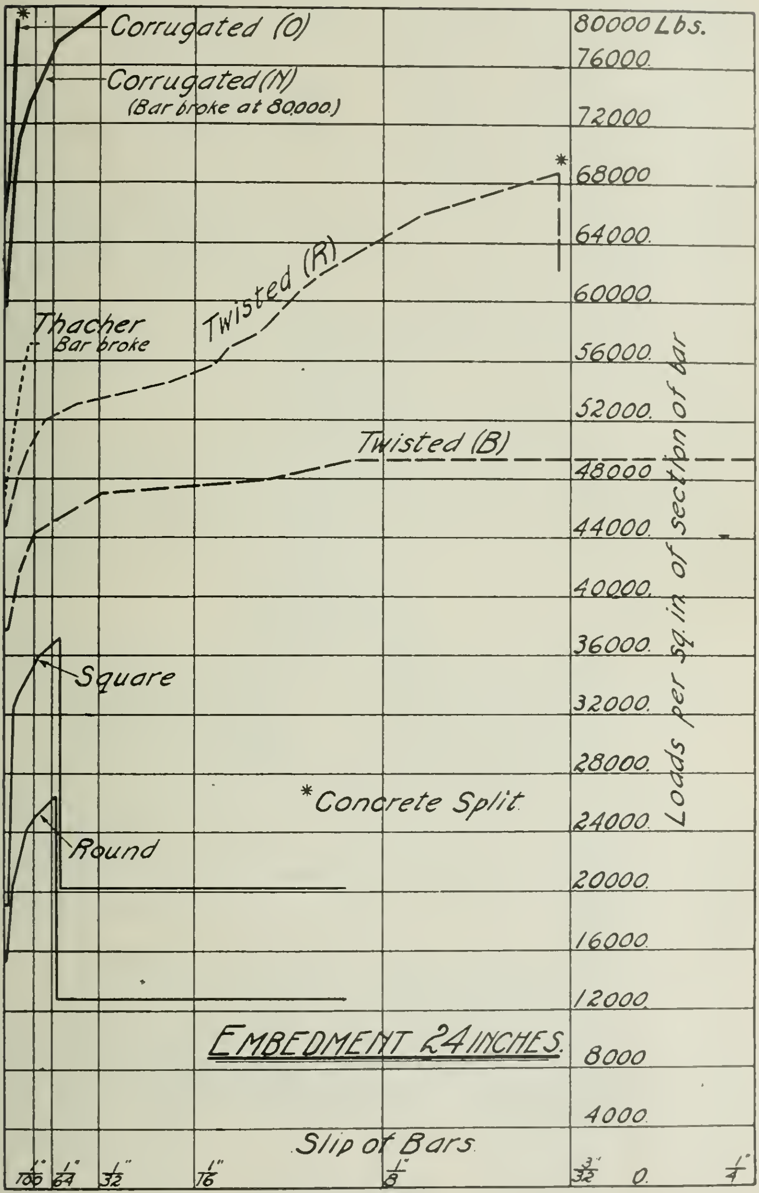


PLATE IV. RELATIVE EFFICIENCIES OF BARS EMBEDDED 24 INCHES.

that the "concrete prisms were secured in the jaws of the testing machine between V-shaped wooden cushions, against which a sufficient compressive force was applied to hold the specimens in place against the tensile pull on the bars." The report goes on to say, "this lateral pressure in the sides of the prisms prevented their splitting lengthwise during the tests and in some degree probably resulted in applying pressure against the sides of the embedded bars." In the writer's opinion this was an unscientific way in which to make such tests, as the lateral pressure of the jaws enormously increased the friction bond between the bars and the concrete and vitiated the results as a consequence. The effect would be most marked upon the adhesion or bond of the twisted bars as they depend for bond entirely upon the wedging action of the inclined planes which the sides form because of the twisting. As a consequence these results are entirely at variance with the results obtained by Prof. Spofford at the Massachusetts Institute of Technology, Prof. Constant at the University of Minnesota, and Prof. C. E. DePuy at Lewis Institute. Moreover, none of these reports except Prof. DePuy's brings out the fact of how much the bars slip before the maximum load is reached and this is a most important feature to consider in bond tests.

The writer desires to express his appreciation of the very careful and scientific manner in which Prof. DePuy conducted this series of tests.

Report of Tests

Made at Lewis Institute, Chicago, September, 1906.

OBJECT OF THE TESTS.

The object in making these tests was to determine the relative strength of bond between concrete and steel for different shaped bars, when the quality of concrete was uniform and the lengths of embedment the same for each of the several different kinds of bars Also to measure the amount of slip, as well as the loads or stresses causing the slips.

SCOPE OF THE TESTS.

In order to make the results comparable bars were secured for the tests having as nearly as possible the same average area of cross section and weight per foot as shown in Table I. There were seven kinds of bars tested and five lengths of embedment of each kind The lengths of embedment were 8, 12, 16, 20 and 24 inches for each kind of bar.

TABLE I.—Description of Bars Used in Tests.

Bars	Size Inches	Weight per foot lbs.	Average Area sq. in.	Average Perimeter Inch
Round	11/16	1.284	.378	2.17
Square	5/8	1.322	.390	2.50
Twisted (B)*	5/8	1.343	.395	2.51
Twisted (R)†	5/8	1.345	.395	2.51
Thacher	3/4	1.310	.385	....
Corrugated (N)‡	5/8	1.250	.368	2.43
Corrugated (O)¶	3/4	1.443	.424	2.60

† Ransome 2.8 twists per foot.
* Buffalo Steel Company 2.3 twists per foot.
¶ Old Style.
‡ New Style.

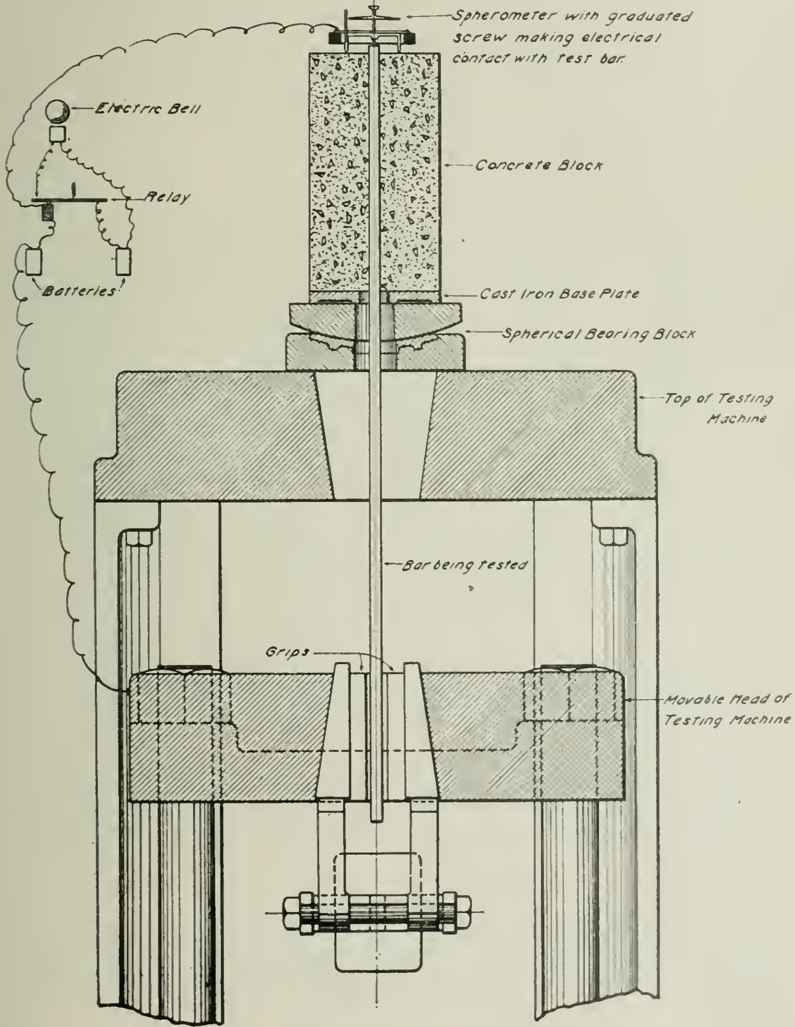


FIG. 1—APPARATUS FOR TESTING BOND BETWEEN CONCRETE AND STEEL.

APPARATUS USED.

The apparatus used is clearly indicated in Fig. 1. The concrete blocks were cylindrical with a diameter of 6 inches and 8, 12, 16, 20 and 24 inches long. Each concrete block had a cast iron base plate, turned to a true face. These blocks were supported upon a spherical bearing block on the top of an Olsen testing machine so that the specimen could be properly adjusted from a direct pull on the bars. The lower projecting end of the bar was gripped into the movable head of the testing machine. The upper end of the bar projected ¾ of an inch above the top of the block, while upon the concrete block rested a spherometer with the graduated screw brought into contact with the upper end of the bar being tested, thus closing an electric circuit. As the load came on, the slightest slipping of the bar in the concrete would break the electric circuit, causing a bell to ring until the graduated screw was turned down and the circuit closed. By this means it was possible to measure very accurately the movement of the bars and the load causing the same.

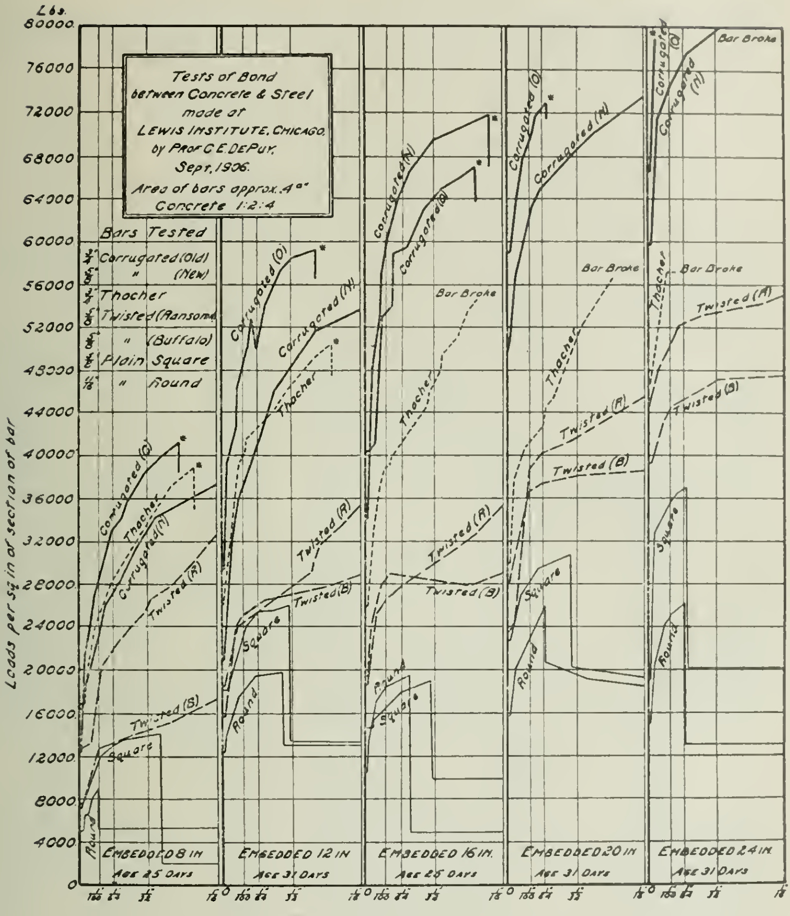
MATERIALS.

Table I gives the general description of the bars used. The round and square bars were of steel furnished by Jos. T. Ryerson & Sons, steel merchants, Chicago, and taken from their regular stock of structural steel bars. The twisted bars (B) were furnished by the Buffalo Steel Company. The twisted bars (R) were furnished by Messrs. Hough & Company, Chicago representatives of the Ransome Concrete Machinery Company. The Thacher bars were furnished by The Schofield Company, Philadelphia, and the Johnson Corrugated bars were furnished by Condron & Sinks Company, Chicago representatives of the Expanded Metal & Corrugated Bar Company. The Ransome twisted and the Old Style Corrugated bars were covered with a thin coat of rust but free from scales of rust. The other bars were all fresh from the rolls and free from rust.

The concrete was hand mixed with great care after the proportions had been accurately measured. The mixture was one Atlas Portland Cement, two coarse sand and four broken lime stone, of ½ inch and under, without dust. This was mixed to a fairly wet concrete, one that would easily enter the moulds and could be churned readily with a small iron rod. All the concrete used was mixed in one batch. The sheet iron forms in which the blocks were moulded were removed about one week before testing. The tests wre made whn the concrete was 25 days old for the 8 and 16 inch embedments, and when the concrete was 31 days old for the 12, 20 and 24 inch embedments.

RESULTS OF TESTS.

The results obtained are graphically shown in Figs. 2 and 3 and tabulated in Tables II and III. These diagrams show the results of all the tests, with a maximum slip of 1/16 of an inch. Where the



*Concrete Split.

FIG. 3—RESULTS OF TESTS OF BOND OF SEVEN KINDS OF BARS AND FIVE LENGTHS OF EMBEDMENT RANGING FROM 12 TO 38 DIAMETERS. LOADS IN LBS. PER SQ. IN. OF *EMBEDDED SURFACE OF BARS* AND SLIPS IN FRACTIONS OF AN INCH.

maximum load or stress on the bar was not reached within a slip of 1/16 of an inch, the curves would extend beyond the limits of these diagrams. In Fig. 2 the stresses or pulls on the bars are reduced to pounds per square inch of the cross sections of the bars, while in Fig. 3 these stresses or pulls on the bars are reduced to pounds per square inch of the embedded surface of the bars. In tables II and III the actual stresses on the bars with the corresponding slips are given, first in pounds per square inch of section of the bars, and second in pounds per square inch of the embedded surface of the bars. As there was no way of readily determining the surface areas of the Thacher bars, these are not included in Fig. 3 and Table III.

TABLE II.

RESULTS OF BOND TESTS.

Stresses on bars in pounds per square inch of cross section.

Embedment	8″	12″	16″	20″	24″
Slip not more than 1/100 inch.					
Round	9,200	18,700	18,900	23,000	24,800
Square	11,900	24,300	16,800	28,000	35,200
Twisted (B)	12,700	25,400	28,800	36,500	44,300
Twisted (R)	19,400	24,600	26,000	38,300	50,600
Thacher	25,300	40,800	38,900	41,200	57,100
Corrugated (N)	23,800	37,500	60,000	61,500	74,500
Corrugated (O)	29,200	48,000	53,500	69,400	79,000
Slip not more than $\frac{1}{32}$ inch.					
Round	*9,200	*20,100	*19,800	*26,000	*26,500
Square	13,900	*26,200	*19,300	*30,800	*37,300
Twisted (B)	14,400	27,100	29,100	37,900	46,700
Twisted (R)	25,400	27,800	30,000	41,700	53,400
Thacher	33,800	46,600	46,400	50,600	*57,100
Corrugated (N)	33,000	48,400	69,600	68,400	*80,000
Corrugated (O)	38,500	58,000	64,100	*73,000	*79,000
Slip not more than $\frac{1}{16}$ inch.					
Twisted (B)	17,300	29,000	29,200	38,400	47,600
Twisted (R)	32,600	35,400	35,500	45,300	55,100
Thacher	†39,000	†50,200	†56,700	†57,000	*57,100
Corrugated (N)	†40,700	54,200	†72,300	72,500	*80,000
Corrugated (O)	†41,300	†58,800	†67,500	*73,000	*79,000
Slip not more than $\frac{3}{32}$ inch.					
Twisted (B)	21,000	32,700	31,500	39,900	48,300
Twisted (R)	39,000	42,800	43,100	51,300	59,500
Corrugated (N)	†40,700	†55,800	†72,300	‡73,300	*80,000
Maximum Stresses on Twisted Bars with Corresponding Slips.					
Twisted (B)	43,000 $\frac{5}{16}$″	57,000 2½″	52,000 1½″	64,500 3¼″	71,000 1¾″
Twisted (R)	41,800 ⅛″	58,200 $\frac{3}{16}$″	56,900 $\frac{3}{16}$″	81,000 ¾″	68,500 $\frac{3}{16}$″

* Developed full strength of bond before slipping $\frac{1}{32}$ inch.
† Developed full strength of bond before slipping $\frac{1}{16}$ inch.
‡ Developed full strength of bond before slipping $\frac{3}{32}$ inch.

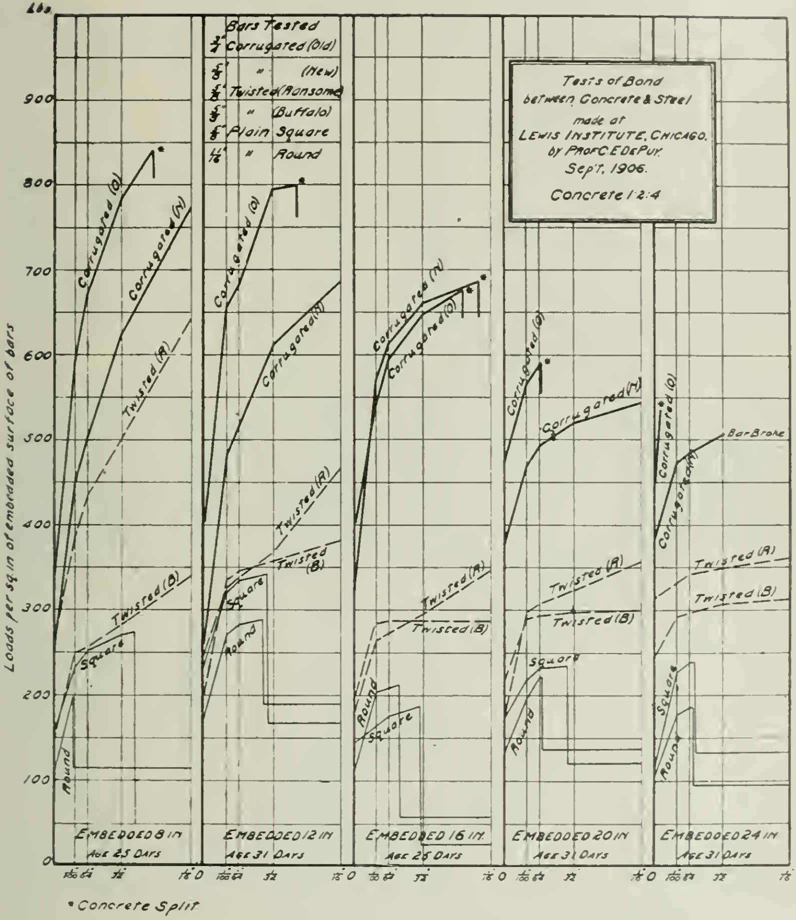


FIG. 2—RESULTS OF TESTS OF BOND OF SEVEN KINDS OF BARS AND FIVE LENGTHS OF EMBEDMENT, RANGING FROM 12 TO 38 DIAMETERS. LOADS IN LBS. PER SQ. IN. OF *SECTION AREAS OF BARS,* AND SLIPS IN FRACTIONS OF AN INCH.

TABLE III.

RESULTS OF BOND TESTS.

Stresses on bars in pounds per square inch of embedded surface of bars.

Embedment	8″	12″	16″	20″	24″	Av.
Slip not over 1/100 of an inch.						
Round	198	269	203	198	178	209
Square	232	316	164	218	229	232
Twisted (B)	250	334	283	288	291	289
Twisted (R)	382	324	256	312	332	321
Corrugated (N)	452	474	569	467	471	487
Corrugated (O)	594	651	545	565	535	578
Slip not over 1/32 of an inch.						
Round	*198	*289	*214	*224	*190	223
Square	271	*341	*188	*240	*242	256
Twisted (B)	283	357	287	299	306	306
Twisted (R)	500	366	295	329	350	368
Corrugated (N)	626	612	660	519	506	585
Corrugated (O)	784	786	653	593	535	670
Slip not over 1/16 of an inch.						
Twisted (B)	340	382	287	311	313	327
Twisted (R)	642	466	349	358	362	435
Corrugated (N)	†775	685	†687	550	*506	640
Corrugated (O)	†840	†800	†687	†593	*535	691
Slip not over 3/32 of an inch.						
Twisted (B)	415	430	310	315	317	357
Twisted (R)	766	562	425	405	390	509
Corrugated (N)	†775	‡706	†687	‡556	*506	646
Maximum Stresses for Twisted Bars with corresponding slips.						
Twisted (B)	846	750	512	510	466	
	5/16″	2½″	1½″	3¼″	1¾″	
Twisted (R)	825	765	560	640	449	
	⅛″	3/16″	3/16″	¾″	3/16″	

* Developed full strength of bond before slipping 1/32 inch.
† Developed full strength of bond before slipping 1/16 inch.
‡ Developed full strength of bond before slipping 3/32 inch.

TABLE IV.

RELATIVE STRENGTHS OF BOND.

Relative efficiencies of the bars tested. From Table II, slip not over 1/100 inch. Strength of bond of plain round bars taken as unity in each case.

Embedment	8″	12″	16″	20″	24″	Av.
Round	1.00	1.00	1.00	1.00	1.00	1.00
Square	1.30	1.30	0.90	1.22	1.42	1.23
Twisted (B)	1.38	1.36	1.55	1.59	1.79	1.53
Twisted (R)	2.11	1.32	1.38	1.67	2.04	1.70
Thacher	2.75	2.18	2.06	1.79	2.30	2.22
Corrugated (N)	2.60	2.00	3.18	2.68	3.00	2.70
Corrugated (O)	3.18	2.56	2.83	3.00	3.18	2.95

RELATIVE EFFICIENCIES OF DIFFERENT BARS.

In Table IV are given the ratios expressing the relative strength of bond, or efficiencies of the different kinds of bars as determined by these tests, at the point where the slip did not exceed 1/100 of an inch, the strength of bond of the plain round bar being taken as unity in each case. From the results of these tests the greater efficiency of the bond of corrugated bars is very apparent.

C. E. DEPUY
Professor of Mechanical Engineering,
Lewis Institute, Chicago.

NOVEMBER 14, 1906.

DISCUSSION.

Prof. A. N. Talbot: I have been much interested in this paper. The points brought out in regard to the early slipping of the bar are new to me. and I am not sure what explanation is to be made of it. I was still more surprised, however, to learn that Mr. Condron would admit that a corrugated bar ever slipped. It seems to me that the amount of this early slipping is a subject for investigation. If there is, with the smooth forms of bar, an early slipping, amounting to as much as 1-64 in., it certainly interferes considerably with the action of the bars in a beam. In the tests, however, this first slip came, for the round and square bars, at loads well up to the maximum bond developed for these bars. It may be well to point out, in this connection, that the bond stress developed in the ordinary beam is not generally such as to make it a controlling element; the bond developed in the rods ordinarily used in a simple beam is only, perhaps, say 50 lbs. per square inch, where Mr. Condron gives as the minimum value something like 200 lbs. per square inch with the plain bar, running up to values considerably above that. In the case of restrained beams, the amount of bond developed would be somewhat more, and also in beams with the bars bent up, but in test beams at the ultimate load the largest bond which I have ever found developed in a beam before the beam failed in some way (not by bond) was, as I remember it, 193 lbs. per square inch. In other words, we should have to make a beam with large reinforcing rods, or a beam very short in comparison with its depth, before we should get a large amount of bond. On the other hand, there are cases where bond is the limiting or controlling element in the strength of a beam. Among other important applications of bond resistance is one which I have been looking into lately, where care should be taken in supplying sufficient bond in the case of vertical stirrups used to take web stresses.

When you think of it, all of the rods in use are, to a certain extent, deformed bars. Some two or three years ago we began using the word "bond' in place of "adhesion," and the more I think about it the more I think that adhesion is the smaller part of the connection between the steel and concrete. With smooth bars, we have, to a certain extent, a mechanical bond. To illustrate that, I may mention the results of some experiments made with very smooth steel—tool steel and cold rolled shafting,—in which the amount of bond developed with a 1:2:4 mixture of concrete was something like 140 pounds per square inch, while the same method of testing there was developed with the ordinary plain, round, mild steel rods a bond resistance something like 350 to 400 pounds. The difference is due, I think, largely to the variations in diameter. The tool steel and cold rolled shafting did not vary in diameter at ¼ in. intervals more than .0001 or .0002 in., while in the mild steel rods the variation in the same interval is as much as .0015.

The other point brought up, of the injury to the bond by soaking in water, seems to me is one worthy of investigation and it should not be accepted without further evidence. If the bond is to be injured through soaking in water, we ought to know it. But I am a little skeptical as to its injury as reported.

It may be added that tests of bond resistance made at the University of Illinois in 1905-6 with round mild steel rods encased in 1 : 2 : 4 and 1 : 3 : 5½ concrete and 60 days as the age at test, gave results having a general range from 350 to 450 lb. per sq. in. The lowest individual result was 342 lb. per sq. in. and the highest 477 lb. per sq. in. No effort was made to find the load at first slip. Mr. Condron's tests were made at an age of 25 to 31 days which may account for the lower values obtained. The tests made at the University of Illinois are recorded in Bulletin No. 8 of the Engineering Experiment Station.

Mr. W. M. Torrance: I should like to ask Mr. Condron how long it took to fill the concrete moulds. In the paper he states that they were all mixed in the same batch of concrete. It seems to me that while the first of the moulds were being filled with part of the concrete, the balance of the concrete would have had time to take its initial set. there having been, as I understand it, thirty-five moulds in all to fill.

It is true that the block of concrete in which the rods are embedded should not be held on the side instead of simply on the end for testing, because in practice the concrete is usually held in position by the adjacent concrete. It does not have a chance to distort laterally the way it would in these tests.

Mr. H. P. Boardman: With regard to that last point about supporting the concrete laterally, I should think, in case of a concrete beam where the steel comes within one or two inches of the surface, it is very far from having lateral support and even less lateral support than the test shows.

Mr. W. L. Abbott: There was a question brought up in the discussion of Mr. Chamberlain's paper that I should like to have answered: Does steel rust or deteriorate in concrete? I will ask Prof. Talbott to give us his opinion in that matter.

Prof. Talbot: I think the general opinion is that concrete is a preservative of steel, provided there is nothing in the mortar or the concrete to interfere with that preservative action. In the case of certain types of cinder concrete, especially where there is sulphur as an active agent, the steel has been reported to be eaten out considerably, but so far as the action of water, or of repeated wetting and drying out, or the effect that air has on the steel, is concerned. I think there is nothing on record which would indicate that in the ordinary type of concrete the steel will not be preserved permanently.

Mr. C. H. Cartlidge: In this connection. it is the general belief among engineers that concrete is one of the best preservatives of steel. if not the best. The speaker has had some experience tending to fix him in this belief. It is well known that concrete has a very alkaline reaction and the action of oxygen on steel is an acid one and that without the presence of acid the transformation to oxide of iron is not possible. It is therefore impossible to rust iron in a strongly alkaline solution. The speaker has known of cases in which water seeping through concrete after it has been in place for fifteen years is still very strongly alkaline and the iron upon which this water drips is as bright and clean as when put in and is entirely free from corrosion of any sort.

Mr. Condron: Referring to Mr. Torrance's questions, I can assure him he need have no fears about the concrete having set while going into the moulds, as it took only about thirty minutes. There was not a great deal of concrete—somewhere in the neighborhood of 8 cu. ft.—so the setting was not a serious matter.

With reference to the other question, I think it has been answered already. It is customary to place reinforcing material in beams and slabs and other construction from a fraction of an inch to an inch and a fraction from the face of the concrete. In these tests the bars were uniformly 3 in. from the face of the concrete, and they therefore had more support from the surrounding concrete than would be the condition in ordinary construction.

Mr. Torrance: I should like to take issue with Mr. Condron in regard to the conditions occurring in practice as to the holding of a bar liable to be pulled out of concrete. In a usual reinforced concrete slab it is true that the reinforcement is very close to one surface, but almost always there is a cross reinforcment in this same plane, and on the other three sides of the bar the thickness of the concrete is such as to hold the rod laterally much more efficiently than would be the case in the 6 in. cylinder tests conducted by Mr. Condron.

In regard to the wetness of the concrete, it occurs to me that the concrete may not have been so wet as is used in the best reinforced concrete work. Twisted bars require, to get the full strength of bond, a wetter concrete than would be required with the corrugated bar to obtain this bond. It might be, if the concrete had been made wetter, the twisted bars would have shown better results.

Mr. L. K. Sherman: I would like to ask if this slipping of the bar might not be due to the compression of the concrete immediately surrounding the bar, which is carried down as the bar is drawn down, and ran out to nothing or a small quantity when it reached the legs of this instrument on top?

Mr. Condron: It is due to something, but just what, I cannot say. A plain bar has many inequalities and a roughness of surface. These bars were taken from stock and were clean, but had the usual mill surface. Undoubtedly small particles of cement mortar entered the depression in the surfaces, and as the load came on, these particles have to adjust themselves. In the case of the corrugated bar you have surfaces which project from the main body of the bar about 1-16 in. and form abrupt shoulders to bear directly against the concrete, so resisting all slipping action.

Prof. Talbot: The point raised by Mr. Sherman is an interesting one,—whether this measurement represents an actual slip or whether it is due to a deformation of the concrete itself, between the point where the bar touches it and the place where the feet of the spherometer are connected.

Mr. Sherman: I would ask whether this was not due to a certain amount of elastic action in the concrete which, if the pull had been removed from the bar, might not have allowed the bar and concrete to come up again. Of course, after reaching 1-16 in., that is past the stage, but for a smaller amount it might be an elastic effect.

Mr. Abbott: In the course of your experiments did you release the pressure for a time to see if it would have any effect?

Mr. Condron: That was not done as part of the experiments, but in one or two cases a delay was necessary in making the tests, and the load was taken off. When the load was put on, we found there was just exactly the same reading, showing there was no apparent backing up. We considered this point, but the diameter of the circle in which the three legs of the spherometer stood was about 2½ in. and the diameter of the ⅝ in. square bar will be not far from ⅞ in. So you will see that the distance from the long diameter of the bar to the point of the spherometer is reasonably small, and if there was such a deflection, it would be microscopical. The uniformity of results seems to indicate that there was this gradual breaking down movement, or readjustment of the concrete in order to resist this shearing action between the concrete and the surface of the bar. Whether the surface is a reasonably smooth one or one that is distorted, it is this breaking down or compression in the concrete itself which would be reasonably expected to cause a movement of the bar at comparatively low loads.

THE THEORY OF THE DESIGN OF RAILWAY FREIGHT TERMINALS.

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Presented January 23, 1907.

THE DEMANDS UPON A FREIGHT TERMINAL YARD.

The general purpose of legitimate railway construction is to provide facilities for the forward movement of traffic. In a freight terminal yard, this means the facilities to receive incoming freight trains, rearrange the individual cars and their contents in proper order for going forward, and to deliver the cars so arranged to road crews or switching crews for the proper forward movement.

The movement through a terminal yard to accomplish this purpose is more or less similar for all classes of business, and advisable differences in the outline and dimensions of yards are for the purpose of expediting and economizing the operations to suit these varying classes of business; in nearly all cases, however, the yard arrangement desirable for effective operation is adversely affected by local conditions, such as the lay of the ground, the position of connecting railway lines, and permanent construction and allied considerations, to all of which the yard design must be adapted.

The design of a terminal yard must be adapted to rapid and economical, as well as to the proper, movement of cars for the forwarding of traffic; such a statement seems so clearly a vital consideration as to be a truism; nevertheless, these requirements of a terminal yard are not fulfilled in the majority of terminals examined by the writer. The time of ordinary freight through a terminal yard should not and need not exceed four hours, from the time of receipt until departure; expedited freight can readily be put through in one hour's time; and freight that must be transferred, rearranged, shifted or otherwise given extra handling, should not be detained to exceed twelve hours. These requirements as to time are not only essential for economy, but for the conditions of competition as well.

The cost of moving freight through terminals can be held down to less than fifteen cents per car for all operating charges including breakage of cars. The actual cost per car on the same basis in the average yard probably approximates thirty cents. The difference

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This article is respectfully submitted at the request of members of the Western Society of Engineers, with whom the writer has been associated in work, by permission of the Engineer of Construction of the Missouri Pacific System, and the Chief Engineer of the Lake Shore and Michigan Southern Railway, in the service of which Companies this subject has been studied.

between these two figures is the saving that efficient design of trackage, grades and facilities effects.

There are a number of auxiliary demands upon freight yards Partial carload lots of freight brought in by different trains and from different towns, should be consolidated to the full economical capacity of individual cars, so no unnecessary cars will be hauled forward.

Cars of foreign lines for the use of which to the destination of their loads the per diem charges, or penalty charges (assessable under the general car service rules of this country) will aggregate or exceed the cost of labor for transferring to a home car, should usually be transferred to home cars at the receiving terminal, unless the car situation prevents.

So-called way-freight should be assembled from the different odd cars that bring it, at the transfer platform of the last division terminal prior to delivery, and there loaded in station order in cars, to permit economical and convenient unloading and minimize losses.

Cars of perishable freight require icing; cars of stock require water, feed and often rest and sometimes transfer to different types or ownership of cars. Cars of potatoes and certain other perishable shipments must be housed at times in the winter to prevent freezing.

With all these demands in view, the amount of traffic to be handled daily must be considered in deciding the general type of yard to design.

THE GENERAL TYPES OF TERMINAL YARDS.

The bulk of work in a freight terminal yard is the separating or classifying of cars. This is accomplished by switch engine service in some one of several ways. The ordinary method of pushing and pulling, or as it is more commonly known, the "kicking" method, is the best known. It is adaptable to almost any lay of ground, costs the least in first construction and within the limits of effectiveness, when well handled, a yard so designed does excellent work. Only a limited number of cars can be handled by this method, and these at a higher cost of operation and higher cost for breakage of merchandise and excessive damage to equipment.

The "poling" method has been used as an improvement on the "kicking" method, to lessen the damage claims, and damage to cars, as well as to increase the capacity of the yards. It requires an extra track parallel with the ladder to which the body tracks of the yard connect, and requires these two tracks to be tangent or nearly so; its first cost is accordingly somewhat greater than that of a kicking yard, and it demands more favorable ground than the kicking yard. It will handle about 100 per cent. more traffic than a kicking yard, at a somewhat smaller expense per car, *if well* *handled.* This last clause must be clearly remembered, in judging of the success or failure of a given poling yard. The almost irresistable tendency is to attempt to handle poling yards with an insufficient force of switchmen, and the resulting breakage of cars and contents has reacted against this general method of switching.

The application of the power of gravity to give cars the forward movement to carry them into their respective classification tracks, has developed sufficiently so that it may be confidently stated that this method is the best and the only one, so far attempted, which will handle heavy business speedily, economically and satisfactorily. The past decade has seen the construction of yards where the entire motive force for giving cars the initial impulse forward for quick movement into their respective tracks, and the continuing impulse to carry them well ahead on these same tracks, has been secured by a clever adaptation of the force of gravity. In speaking of these latter years of progress, there is no desire to discredit earlier efforts.

Credible advice has come to the writer of excellent working gravity yards constructed in the early '70's, at Hoboken, N. J., for handling tidewater coal for the Lackawanna line, and a later and sucessful use of gravity at the Honey Pot yard of the Pennslvania R. R., Sunbury, Pa., for making up coal trains. The conditions at each of these points are so widely different from those of the typical freight terminal, that the only application pertinent to an article that should be brief as possible, is their corroboration of the usefulness of the general principles of gravity. Full statistics of the bulk of the yards of this country can be found in the interesting article by Mr. W. C. Cushing, Chief Engineer Maintenance of Way, Southwest System, Pennsylvania Lines, upon the subject of yard design, published during May, 1905, in various magazines.

THE THEORY OF DESIGN OF A FREIGHT TERMINAL.

There may be said to be four principal handlings of freight cars, and one auxiliary handling of a portion of them, involved in the movement of all traffic through a freight terminal; the occasional solid train that goes through with no change in its make up except to change engines, cabin cars and crews being an exception. These handlings are:

1. The receiving of incoming trains and the work incidental thereto.

2. The separating or classifying of cars, more commonly known as "breaking up" trains.

3. The grouping into train order for advance movement, of the separated or classified cars, commonly known as "making up" trains.

4. The forwarding of trains, and the work incidental thereto.

The auxiliary work is that already adverted to, viz.; the rearrangement, consolidation and transfer of freight for reasons of economy, safety, or because of the need of repairing the cars;

the icing of perishable freight, or the feed, water and rest needed by stock. For these operations, facilities are needed as follows:

THE RECEIVING YARD.

For receiving the incoming trains, a so-called "receiving yard" is needed. This yard should have tracks of a sufficient length to admit the maximum length trains that can be anticipated, without doubling in. For this estimate, a car's length is assumed at forty feet, and engine's length at seventy-five feet and a caboose to suit the standard of the railway; in addition there should be provided space for a double header engine, and several hundred feet leeway for inexact stopping of trains. As there will be many short trains, these long tracks should be provided with a reasonable proportion of crossovers to thoroughfares so that a short train will not block the entire length of a track for a maximum length train. Also, as a number of trains have cars of perishable or live freight directly behind the engine, trackage outlet independent of the regular outlet of the receiving yard should be provided to afford a direct and immediate movement to the icing plant or stockyard, so the road engine can quickly take this high grade freight to these points.

The time of a train in a receiving yard under average conditions should not exceed one hour, for the purpose of cutting off the road engine and the caboose, the inspection of cars for defects, and the coupling on of the switch engine in readiness to commence breaking up the train. This hour of time can very wisely be used for making the light repairs to the cars needing such, and as a usual thing, about one-half of the defective cars in certain large yards are repaired during this period of inspection. This is accomplished by stationing a squad of car repairers at intervals along the track the train is entering, with a few tools and supplies. This work can be done with the tracks on thirteen-foot centers, but where there is space available, fourteen-foot centers are preferable.

The number of tracks in such a yard should be sufficient to hold the accumulation that may result from any likely derailment in the advance movement through the general yard system, or congestion from other causes.

An important and very necessary adjunct to a receiving yard, is the trackage for that ever-present evil of freight traffic, the "hold" business. There are always cars without way bills, cars of unconsigned lumber and unconsigned coal, to be held for billing at any terminal; these cars should never be allowed to block a receiving yard. Their forward movement is ordered day by day, a car or more here, and a car or more there, from the strings of cars on the hold tracks. It is manifestly bad operating policy to classify an entire string of cars either by gravity over a hump, or by poling to secure an occasional car for which billing has come; it is also bad policy to dig out these occasional cars from the long strings of cars by the push and pull method. Accordingly, there should be placed alongside the receiving yard, a sufficient number of moderate length "hold" tracks, which can be switched by the push and pull method; these tracks should be under control by the most generous proportion of drill tracks of the entire yard system. The writer makes it a practice for the usual coal hold yards to equip each four body tracks with an independent ladder drill track at each end. There will, of course, come times when a sufficient number of billing orders arrive, to justify classifying an entire string of cars from a given track; the proper trackage for such a contingency should be provided.

THE SEPARATING OR CLASSIFYING YARD.

When solid trains of through freight come into a yard they can go onward as received after inspection, change of crews and incidental work, without being broken up. For this class of trains a by-pass line from the receiving yard to the forwarding yard unobstructed by the usual yard work, should be provided. Nearly all trains, however, contain cars of local freight for the particular division point where the yard is located, or of interchange freight for other railway lines; and cars of company supplies, bad order cars and improperly loaded cars are usual. Different ruling grades or motive power assignment on the next division, may require the train lightened or filled out. The yard may also be a junction for diverging lines of the railway, and trains will usually have freight for each line. For these reasons, the cars of an incoming train must be separated, assembling on one track the cars for a given destination or class of yard work, on another track, cars for another, and so on until all cars for a similar destination are together.

For this separation work, there is required such a number of tracks as the number of classifications suggest, after considering the influence of acceptable operating demands, the yard space available, the second switching needed and local conditions. It is very difficult to set a fast and hard rule as to the number of tracks needed without a thorough knowledge of the situation at the proposed terminal, and it would render this article unduly tedious to set forth all the deductions from the various contingencies that may develop at different points. Briefly, it may be said that the separating yard should be designed so that, so far as possible, all the separating of different cuts of cars be accomplished when first dropping them into the separating yards; and at the outlet end of the separating yard, the work so far as possible should be only that of bunching together these groups of cars from the different tracks into a train lot. In spite of the most favorable design, a certain amount of second switching at the outlet end of the separating yard is necessary to put cars into train order. Where this amount is small, it can be accomplished by the push and pull method by providing the outlet end of the body tracks with a good ladder drill system so that engines can work simultaneously without delaying each other. If this "tail switching" aggregates a considerable amount of the traffic or must be done quickly, the cars should be taken to a second separating yard, more properly called a "grouping" yard, or classifying yard, where the grouping into train order can be done without interfering with the functions of the main separating yard. This latter grouping yard is particularly needed where there is a large proportion of fast freight to be handled. The length of the individual tracks in a separating yard is usually made equivalent to a maximum train length, and excellent operating men urge this as advisable at the present day. The writer believes that in nearly all cases, such tracks should be of about 60 per cent. the length of maximum trains, except where traffic is so regular and heavy that a maximum train length of cars which require no grouping into train order can be expected to accumulate within the time limits that such cars can properly be held before forwarding. This belief is based upon the unfavorable working of long tracks in existing yards examined by the writer, and upon the following theory: a classifying or separating yard is not a storage yard, nor should it be so used in any part, as such use blocks the particular tracks from receiving additional cars, as the work of separation proceeds. That portion of the traffic that is held for bills or is unconsigned should be moved to a "hold" yard, as earlier outlined. All other freight should be separated, made up into trains and forwarded as a continuous movement, for the plain business reason involved; these reasons are, the better use of the equipment, the speedier forwarding of freight, and the smaller force of yard men thereby required. A train is ordinarily made up by coupling together the accumulation of cars on a number of the tracks of the separating yards, until a train lot is assembled. If it is a fast freight train, the high-class freight that is accumulated on the different tracks is coupled together and enough cars of ordinary freight put on at the rear end to fill out the train to the desired tonnage; the road crew couples on and the train starts on its road movement.

This process is continually recurring. By so handling the train make-up work, there is a minimum delay to the cars and a smaller force of engines and men is needed, than if the work were concentrated after certain intervals of waiting for train lots of a single character to accumulate. Granting that this general statement of conditions applies to a given freight terminal, it is clear that no good end would be served by constructing long tracks in the particular separating yards, and it is likewise clear that much more rapid coupling together of accumulations of cars on each of a number of tracks can be done if those tracks are of moderate length than if they are of the length of a maximum train. Furthermore it is, of course, less costly to construct and maintain a yard of moderate length separating tracks, than of longer ones, whether the yard be on a level grade or a gravity yard; similarly it is clear that it is less costly to separate trains into a yard of short tracks than of long ones.

In starting this discussion of the length of the tracks the writer said that the statements to follow applied "except where traffic is so regular and heavy that a maximum train length of cars which require no grouping into train order, can be expected to accumulate within the time limits that such cars can properly be held before forwarding." This proviso should be distinctly considered, for this feature has often proven a stumbling block in a yard design.

There are only a few railways in this country whose business at the largest gateways is so heavy as to justify the adoption of the above exceptions. At the St. Louis gateway for instance, the Gould System of Railways handle about 66 per cent. of the total aggregate business of the twenty-three railways entering that important gateway; nevertheless, the rapid forwarding of cars demanded by the conditions of competition, absolutely forbade any construction of long tracks in the separating yards to hold accumulations of cars for the same destination. Accordingly, the separating tracks at Dupo were established at thirty-five car lengths each, basing this upon a train length of sixty cars as the maximum advisable for belt line movement. At Buffalo, the slow freight of the Vanderbilt System accumulates rapidly in train lots, with practically no train order work needed; accordingly certain tracks were provided to hold one hundred cars each in the separating yards; these are supplemented by shorter tracks for fast freight business.

At Pittsburgh, traffic probably accumulates fast enough to justify such maximum length tracks; also, at the heaviest coal receiving points on the eastern lines of the Pennsylvania R. R. and the New York Central System, and possibly other lines, and at the principal tidewater points the same is undoubtedly true.

The tail switching at the outlet end of the separating yards has already been mentioned. This second switching is very much of an evil at best, and to minimize it, the outlet end should be arranged for the most advantageous kicking switching. The ladders so provided must give perfectly free movement for simultaneous drilling.

THE FORWARDING YARD.

When a train is made up, it is taken to the forwarding yard where the air brakes are tested and coupled together, the caboose and road engine coupled on, the starting order or signal given and it moves forward on its way to destination. For this purpose is required tracks to hold the maximum lengths of made up trains; these tracks in turn should have crossovers to hold two short trains on a single track. Lines of compressed air pipe should be provided. The caboose tracks should be close to one end of this yard. Some railways prefer that the cabooses be kept near the outgoing end of this yard, so the caboose can be put on by gravity or otherwise as the train pulls out; other railways insist that the cabooses be put on the train before it starts. The writer sees no marked preference either way, if skill is used in designing the tracks. Thoroughfare tracks must be provided in sufficient number so that there can be no friction or delay in the pulling of made up trains from the separating yards into the forwarding yard, and in the caboose and road engine movements.

GENERAL DETAILS.

THE TYPES OF FROGS ADVISABLE.

The angle of frogs generally used in yard tracks have been one in six and one in seven. When engines and cars were of comparatively light weight and the purchase of land limited to the smallest tracts that would admit of a working arrangement, there was justification for such angles. Since the Motive Power Departments began flanging all driver wheels, and the weight of engines has increased so much, the sharp leads required by these short angle frogs have been expensive and difficult to maintain, and derailments much increased. This is generally recognized, and easier frog angles are being favored in recent years. In a terminal yard where switching is constant, no frog of lighter angle than No. 8 should be permitted, and this frog only in the portions where the work is done exclusively by yard switch engines. The yard and road engines of the present day will frequently derail themselves on a No. 8 lead in perfect condition. In the receiving and forwarding yards, where the road engines must move, and in the approaches to the humps of gravity yards, the frogs should be No. 9 at the sharpest and No. 10 if practicable. The enormous engines used for hump engines are very destructive of switch leads and will derail themselves frequently on sharp leads. In the ladder leads of separation yards operated by gravity, the curvature of the switch leads must not be such as to bind the cars running around them; a No. 8 frog is the sharpest justifiable, and No. 9 the preferable angle at this point. These general rules as to frog angles may seem hard to follow on a given strip of land; but the evil of their disregard is certain. The writer makes it a practice to make the diverging angle of the body track as large as possible and carry the curve beyond the frog to make up the total central angle. In portions of a yard where there is very little switching, this method can be varied to permit alternate body tracks to act as a subordinate ladder for another body track, thus placing upon the main ladder only one-half the switch leads. This device must not be used in ladders where there is considerable switching, as its use involves delay in work and danger to the switchmen, and is certain to cause side stripping of cars occasionally.

LADDER LEADS.

Ladder leads should be adapted to the needs and use of the body tracks they control. They should be as short as business permits, and the body tracks that one ladder cannot well control should be coupled to another ladder. It is generally conceded by operating men that a single switch engine cannot economically switch more than eight tracks. This rule would make that number the maximum number of body tracks to couple into a single drill track. Plate 2 shows a combination of three units of eight tracks per ladder illustrating the simplest type of classifying yards In such an arrangement three engines could be switching continually without friction. Before accepting the above rule as conclusive in a given case, the number of separations required to put a train into proper order for forward movement must be cansidered. If there are more than six groupings required, and only eight tracks provided, a corresponding amount of temporary bunching and re-switching will be necessary. Conditions often require fifteen to twenty classifications to make up cars into train order, and these conditions must be met satisfactorily, if economical and efficient work is to be secured. At such points, if the separation work is to be handled by the push and pull method, two drilling leads can be designed with half the total number of classification tracks needed, coupled to each ladder; between these two drill tracks should be placed two receiving tracks common to each drill. Upon these special receiving tracks can be placed the overflow groups from one side that are to be later grouped on the other side and vice versa. This, of course, means re-switching, but there is no better solution of this difficulty, and the usual custom is more disadvantageous. Plate 3 indicates a combination of two units of eight tracks per ladder .with the two common tracks between for receiving the overflow cars from either side to meet such conditions.

In the hump yard system, the above rules do not obtain in the gravity portion of the separating yard. Here the motive force that starts each car and moves it forward into and partly through the separating yard, is gravity only; the only work required of the switch engine to effect the separation of the cars is to push a train up to and over the apex of the hump. If the track arrangement and adjustment of gravity ratios beyond the apex are properly designed, the cars will run over a single track throat into the respective tracks of the separating yard faster than it is physically possible to bring them to the apex by the most advantageous track arrangement. Accordingly, there is no object in providing more than a single track throat to such a yard. The usual difficulties with gravity separation yards are due to improper adaptation of gravity, sharp switch leads and unnecessarily curved ladder leads, which cause the cars to bind and either lag or entirely stop before reaching the right point; also excessively long lad ders which call for high humps, slower movement of trains, greater forces of riders and other evils. The question of gravity ratios will be taken up later in this article. The track arrangement should be based upon coupling to a single ladder not more than ten tracks in the very largest yard, and not more than six tracks, if possible, in other yards; if a given hump yard is to have twenty-four tracks, four ladders each with six tracks coupled would be required. If thirty tracks are needed it would be better that eight tracks each be coupled to two ladders and seven each to the other two ladders, as it is seldom advisable to put more than four ladders in a yard, owing to the extra curvature involved in the tracks from the fifth and sixth ladders. This arrangement of four ladders is shown in Plate 4 in comparison with two ladders for the same number of body tracks, and a profile for each, all drawn to the same scale and for similar operating conditions. The advantage of the four ladder scheme is manifest.

In a hump yard the ladder switches at the entrances of the body tracks can be operated, either automatically from a tower at the throat of the yard, or by individual switch tenders. Excellent electro-pneumatic systems for handling these switches are used at various of the larger yards, satisfactorily to the operating officers. On the other hand, the switch tenders are used at other yards with even greater satisfaction. The electro-pneumatic method is the more economical of the two, but has the disadvantage of being slower in operation.

PULL UP ENGINE OR CAR.

In a busy yard there is distinct economy in providing air engine or trolley car to bring the switchman back up to the hump after riding a car to place. Usually some old light engine is assigned to this work. Gasoline cars have been tried, but are so continually breaking down as to be of little value. A trolley car is probably much the cheapest device for this work. For the movement of these cars a separate track should be provided at about midway of the yard; if the yard is a large one, two such tracks may be advisable, with two trolley cars or engines.

THE TRACK SCALE.

There are few questions in yard design more annoying than the proper location for the track scale. At terminal points, where large yards are needed, there is usually a considerable proportion of the total business to be weighed. If this percentage justifies it, the scales can be placed on the hump alongside of and parallel with the regular entrance track to the separating yard, so that the trains containing weigh cars can pass over the scale as they enter the yard. This is the quickest method of weighing. It is, however, a distinct misfortune to all other traffic to place the scales on the hump, as the adjustment of gravity ratios to properly move cars for weighing is not the most advantageous for other freight. Cars can be weighed satisfactorily to the weighing associations, while running free, at the rate of abopt four a minute. If there was a continuous supply of cars available and there were no delays in moving them forward to the hump, this would mean the weighing of 240 cars per hour, or in the ten hours of the days work, 2,400 cars, and in the ten hours of night work, about 25 per cent. less, or a total of 4,200 cars per day. As a fact, however, the interruptions to work are so continual as to cut the daily weighing down to about one-third of this amount. On the other hand, the grades that are suitable for a plain throat track, free from scales, will permit the classification of cars faster than it is possible to bring them up the hump. The writer has seen eleven cars per minute, classified over a well arranged hump until the car supply gave out, and from average results from several yards known to the writer he thinks it safe to count on an average of 3,000 cars per day of 20 hours as readily possible, even under adverse conditions, with an ordinary force of riders, and no special effort. These conditions urge one to attempt to locate the scales elsewhere than on the hump.

In developing plans to be submitted for the Buffalo Terminal Yards of the New York Central Lines, to be located at Gardenville, just southeast of Buffalo, N. Y., where the proportion of cars to be weighed was unusually small, the following scheme was developed; for heavy runs of weigh cars, a scale was placed at the mid-length of an independent track, extending outside of and alongside the general separation yard from its outlet backward to the receiving yard. The weigh cars were to collect on a particular track in the separating yard up to the capacity of an engine to handle readily. They are then pulled out from the separating yard, and pushed backward to the scale track, and weighed as they move over the scale towards the receiving yards. When weighed, they are pushed to the entrance to the hump, ready for re-classification for destination. The easiest way to re-classify is, of course, by gravity, and the cars are in the correct place for moving over the hump for this purpose. The backup movement involved in this scheme of weighing is unfortunate, but is a much less evil than is involved in placing the scale on the hump. For comparatively light business, a distinct improvement in the above scheme for weighing was suggested for the Buffalo Terminal, by Mr. R. O. Rote, Principal Assistant Engineer, L. S. & M. S. Ry. The scale was placed at the mid-length of the outside body track of the general separating yard, and the particular gravity ladder running from the throat of the yard to this track was connected to a thoroughfare track by a trailing switch. After the upper end of the gravity scale track was filled from the scales to this trailing switch, a yard engine ran through to the cars,

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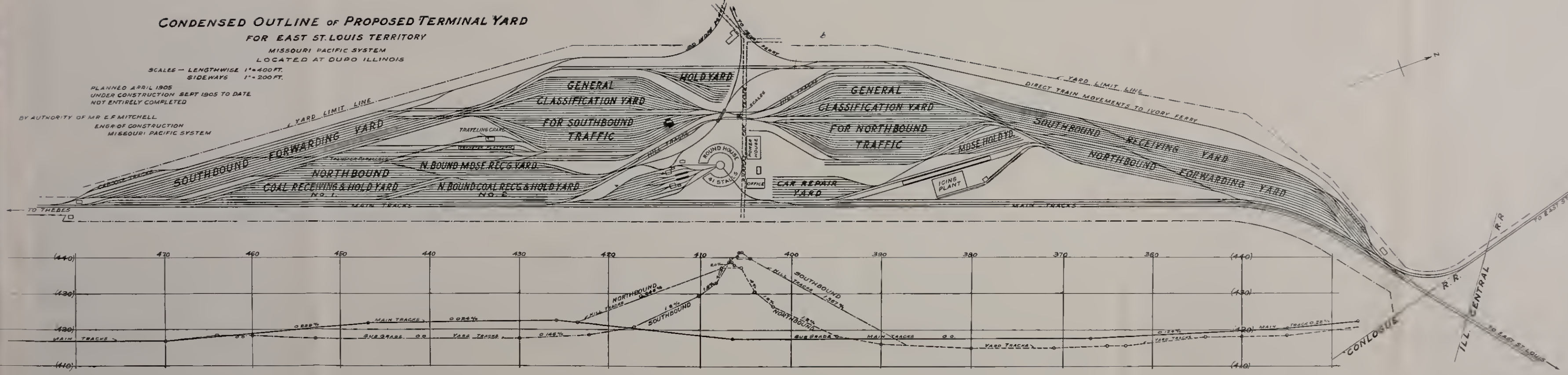

CONDENSED OUTLINE of PROPOSED TERMINAL YARD
FOR EAST ST. LOUIS TERRITORY
MISSOURI PACIFIC SYSTEM
LOCATED AT DUPO ILLINOIS

SCALES — LENGTHWISE 1" = 400 FT.
SIDEWAYS 1" = 200 FT.

PLANNED APRIL 1905
UNDER CONSTRUCTION SEPT 1905 TO DATE
NOT ENTIRELY COMPLETED

BY AUTHORITY OF MR E.F. MITCHELL
ENGR OF CONSTRUCTION
MISSOURI PACIFIC SYSTEM

PLATE 1.

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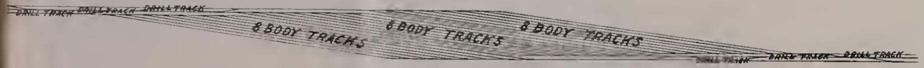
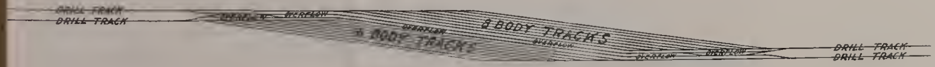


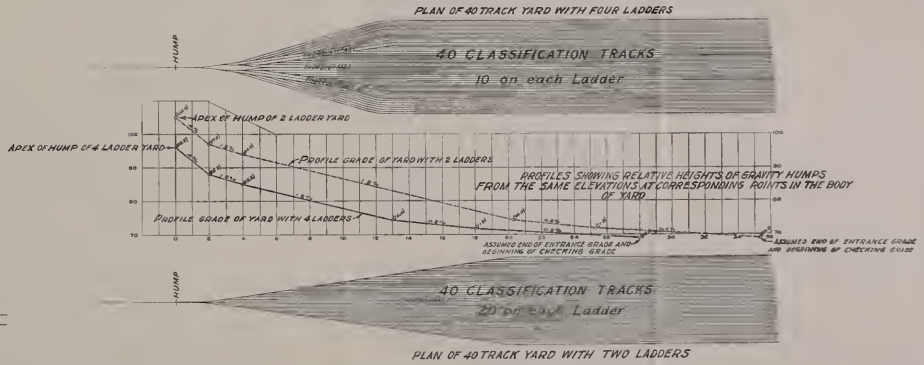
OUTLINE OF UNITS OF TYPICAL YARD FOR SWITCHING BY THE USUAL PUSH AND PULL METHOD
EIGHT BODY TRACKS PER LADDER ADAPTED TO POINTS WHERE SIX CLASSIFICATIONS WILL USUALLY SUFFICE IN MAKING UP TRAINS

PLATE 2.



OUTLINE OF YARD FOR SWITCHING BY THE USUAL PUSH AND PULL METHOD
EIGHT BODY TRACKS PER LADDER ADAPTED TO POINTS WHERE BUSINESS CONTINUALLY REQUIRES MORE THAN SIX CLASSIFICATIONS IN MAKING UP TRAINS

PLATE 3.


PLAN OF 40 TRACK YARD WITH FOUR LADDERS
HUMP
40 CLASSIFICATION TRACKS
10 on each Ladder
APEX OF HUMP OF 2 LADDER YARD
APEX OF HUMP OF 4 LADDER YARD
PROFILE GRADE OF YARD WITH 2 LADDERS
PROFILE GRADE OF YARD WITH 4 LADDERS
PROFILES SHOWING RELATIVE HEIGHTS OF GRAVITY HUMPS FROM THE SAME ELEVATIONS AT CORRESPONDING POINTS IN THE BODY OF YARD
ASSUMED END OF ENTRANCE GRADE AND BEGINNING OF CHECKING GRADE
ASSUMED END OF ENTRANCE GRADE AND BEGINNING OF CHECKING GRADE
100
90
80
70
0
2
4
6
8
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16
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24
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32
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36
HUMP
40 CLASSIFICATION TRACKS
20 on each Ladder
PLAN OF 40 TRACK YARD WITH TWO LADDERS

COMPARISON IN A GIVEN YARD OF 40 BODY TRACKS. OF THE RELATIVE HEIGHTS OF GRAVITY HUMPS BETWEEN THE TWO LADDER METHOD AND THE FOUR LADDER METHOD OF DESIGN

PLATE 4.

pushed them over the scales, then reversed, pulling them back, via the outside thoroughfare around the hump to the receiving yard, and reversing again, pushed them over the hump. This movement interferes slightly with yard operation but can usually be performed to fit in with other work smoothly, and for such amounts of business as it can handle, it is distinctly the best arrangement known to the writer.

THE ADJUSTMENT OF GRAVITY RATIOS, IN A GRAVITY TERMINAL YARD.

The movement of a train of cars up and over a gravity hump, is for the purpose of placing the cars at such a height as to secure, by the aid of gravity, for each cut of cars, a quick start forward as the cut passes beyond the apex of the hump, and momentum sufficient to carry the cut onward through the arrangement of switches into the proper track in the classifying yard, and onward through this track until the lessened grade of the body of the classifying yard causes the cut of cars to stop from the combined friction of the car journals, the resistance due to low joints, poor line and worn rail usual in yard tracks.

Analyzing this movement in detail, it can be resolved into the following elements, each of which is essential and each of which calls for the proper adjustment of gradient and alignment in yard design.

The initial start of a cut of cars is caused by the grade placed just beyond the summit of the hump; this start corresponds to the thrust given cars by the boom of the poling car in a poling yard or to the "kick" given by the switch engine in the ordinary "kicking" yard. This starting grade is usually called the "momentum" grade; and as this entrance point controls all movements into the classification yard, any delay at this point would to that extent lessen the operating capacity of the yard, regardless of favorable arrangements elsewhere. Furthermore, if the momentum imparted is not sufficient to carry the car through the distance it must run at the best rate of speed consistent with safe operation the yard is again limited in capacity. Accordingly, the grade must be sufficient to start the cut of cars quickly forward, and it must impart sufficient momentum to keep the car going. This momentum should theoretically be assisted by sufficient grade beyond the limits of the hump grade to enable the car to run over the switches at the throat of the yard and in the ladder leads and around the curves at these points, until the cut reaches the proper destination track of the yard at the uniform speed, but not to increase the rate of speed. This grade, properly called the "continuing" grade, is an important feature, as the lagging of cars on the ladder leads, resulting from insufficient grade, would limit to that extent the operating capacity of the yards, and in most yards does do so. Other considerations, however, affect a decision as to this advisable gradient, and compel the proper rate to be exceeded to meet difficulties of operation. A hard moving car, although given the proper momentum at the hump, will lag on the ladders and delay other cars following it; and unless the grade of the ladders is sufficient to quickly start forward these delayed cars when the hard moving car has entered its destination track and cleared the ladder, the slow movement of one car will be continued to a serious degree in the following cars. Accordingly, this continuing grade must be steepened for this purpose so that, when needed, it will act as an accelerating grade.

Once in on the destination track of the separating yard, the car should have sufficient momentum to carry it well onward toward the out-going end; and in this latter portion, it should be stopped by the friction of its own movement by lessening or discontinuing the grades. To assist the car in keeping its momentum in the earlier part of this run through the yard, a few hundred feet of grade equal to the friction of the car journals and track condition is provided. This grade is the "drifting" grade. The "checking" grade that follows is very largely determined by the length of the individual tracks of the classifying yard, so that cars may not be stopped too early.

APPLICATION OF THE THEORY OF GRADES.

In deciding what rates of descent will, by the force of gravity, cause the cars to move as above outlined, a number of conditions affecting operation must be considered. In addition to the theoretical grade required to overcome the ordinary rolling friction of cars on tangent, must be added compensation for curvature of switch leads, compensation for the friction due to low joints, worn rails, and inferior line unavoidable in yards; also the extra force of wind against cars on the high portion of the yard must be provided for, and at the hump, in addition to all these considerations, the grade must be adjusted to give a quick start forward.

Also, there must be considered the effect of low temperatures of the winter season on the car journals, and the still more inconvenient feature introduced by the occasional hard running car; freight equipment is subject to hard usage and comparatively scant care, and some cars require more grade to run moderately than others do to run freely. As the slow running car must not be allowed to delay movements, the gradients must be adapted to its condition, and the more freely running cars controlled by the brakes. Furthermore, empty cars start more slowly, run harder and are more retarded by wind pressure, than loaded cars.

Accordingly, in selecting the combination of grades for a given yard, after ascertaining the classes of traffic to be handled, and the special handling involved, the final decision as to the gravity ratios is based on those that will satisfactorily move the hard running cars under adverse conditions of the weather, wind, and track; the free running car, if unbraked, would gain a higher speed on such grades than advisable for safe operation, and the brakes are depended upon for this checking.

In determining the aggregate effect of the elements of compensation, dependence must be placed upon the results of the use of the existing yards of the gravity type.

From the day of the early gravity yard of the Lackawanna Railroad at Hoboken in successful operation in the early '70's, up to the present time, the trying of different gradients has continued and few engineers are yet convinced as to the proper adjustment. The momentum grades that have been used, vary from 0.75 per cent. to 7.0 per cent. for a distance of one hundred feet or more; ladder grades have varied from 0.5 per cent. to 2.0 per cent.; drifting grades have been the usual theoretical rate of 0.4 to 0.5 per cent., and the checking grade has varied from a level to 0.3 per cent. It is said to be the custom of some companies to put up a steeper momentum grade in winter to overcome the effect of the greater friction of the car journals; this has been done at Pitcairn and Altoona, Pennsylvania, but the faster movement of cars caused thereby was so desirable that the winter grades were not cut down when warm weather came, and, the writer understands they continue so today.

With all these considerations must be balanced the danger of smashing cars, due to possible excessive gradients and the failure of brakes or their improper application. It must be recognized, though, from the smashing of cars in yards of the lightest gradients in use, when brakes fail, that it is impossible to design a gravity yard even at great sacrifice of efficiency in operation, that will prevent damage to the unbraked car.

Accordingly, the brakes must be depended upon to control the cars when needed, and the car without a brake, or with a defective brake, must be either herded out for repairs or dropped down into the classifying yard, coupled to the next car for weeding out through the outlet end. As a matter of fact, bad order in handbrakes is quickly detected in the inspection of the train in the receiving yard and usually remedied at once, and little breakage results in a well handled yard for bad order brakes.

After consideration of these matters and examination of the actual working, day and night, good weather and bad, of the principal gravity yards of this country, the writer respectfully recommends as the proper grades the following ratios upon which was based the combination of grades for the Dupo yards of the Gould System:

NORTHERN CLIMATE	SOUTHERN CLIMATE
POINT ON GRAVITY SYSTEM, MOMENTUM GRADE (WITH NO SCALE ON HUMP TRACKS	
FOR LOADED CARS	
200 feet of 3.0 per cent grade.	200 feet of 2.5 per cent grade.
FOR EMPTY CARS	
200 feet of 4.0 per cent grade.	200 feet of 3.0 per cent grade.
*MOMENTUM GRADE WITH TRACK SCALE ON HUMP TRACK	
25 feet effective 4 per cent grade, followed by scale on 1 per cent grade, followed by easy vertical curve, say, 50 feet in length, followed by 200 feet of 3.0 per cent grade for loaded cars, or 200 feet of 4.0 per cent for empty cars.	25 feet effective 4 per cent grade, followed by scale on 1 per cent grade, followek by easy vertical curve, say, 50 feet in length, followed by 200 feet of 2.5 per cent grade for loaded cars, or 200 feet of 3.0 per cent for empty cars.
LADDER GRADE FOR LOADED CARS	
0.9 per cent throughout.	0.7 per cent throughout.
FOR EMPTY CARS	
1.2 per cent throughout.	1.0 per cent throughout.
CONTINUING GRADE THROUGH YARD—FOR LOADED CARS	
0.3 per cent.	0.2 per cent.
FOR EMPTY CARS	
0.4 per cent.	0.3 per cent.
CHECKING GRADE	
Between 0.0 and 0.2, dependent upon length of tracks.	

In case curvature exceeding eight degrees per hundred feet is used in any switch leads from the hump downward, compensate for the excess over eight degrees beyond the grades above suggested at the rate of 0.06 per cent. per degree of central angle per station at the point; and in case of any curvature in the ladder track or body tracks of the separating yards, it should be compensated for at the rate of 0.04 per cent. per degree of central angle per station at the point. Instead of the usual method of compensation, the friction of curvature of switch leads can be provided for by dropping the body tracks downward by a stiff vertical curve just beyond the end of the frog.

The recommendation of compensation for curvature is the result of observation of the lagging of cars in yards where compensation has been omitted. The rate of compensation is placed higher than for main track because of the poorer conditions that prevail in yard track.

No less important than the adoption of proper ratios of grade is the placing of the apex of the hump as close as possible to the entrance of the yard; so vital is this consideration that a yard, correct in all other respects, will be a failure if this point is ignored.

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*When scales are required on the hump, put two tracks over the hump, one for the plain track movement, one for cars to be weighed, combining the grades at a point reaching the entrance to the yard.

These conclusions are based upon examination of the following yards, whose important grade characteristics are mentioned:

RAILWAY	LOCATION	YARD	GRAVITY		RATIOS
			HUMP		LADDER
Chicago Union Transfer Ry.	Clearing, Cook Co., Ill.	Both Ways	200 ft.	4.0%	0.9%
P. F. W. & C. Ry.	55th St., Chicago.	Eastbound	150 ft.	3.0%	0.5%
		Westbound	150 ft.	3.0%	0.5%
P. C. C. & St. L. Ry.	Logansport, Ind.	Eastbound	*125 ft.	2.4%	0.5%
		Westbound	*250 ft.	1.45%	0.43%
L. S. & M. S. Ry.	Elkhart, Ind.	Eastbound	200 ft.	4.0%	1.0%
		Westbound	200 ft.	4.0%	1.0%
L. S. & M. S. Ry.	Collinwood, Ohio.	Eastbound	200 ft.	4.0%	1.0%
		Westbound	200 ft.	4.0%	1.0%
P. F. W. & C. Ry.	Conway, Penna.	Eastbound	210 ft.	3.0%	1.0%
		Westbound	480 ft.	1.8%	10.6%
Pennsylvania R. R.	Altoona, Penna.	Eastbound	185 ft.	4.5%	0.9%
		Westbound	125 ft.	4.0%	0.92%
			100 ft.	2.5%	1.3%
P. C. C. & St. L. Ry.	Scully, Penna.	One only	100 ft.	2.5%	1.3%
Pennsylvania R. R.	Harrisburg, Penna.	No. 4 Westb'd.	150 ft.	3.6%	1.2%
"	Fairview, Penna.	Eastbound	150 ft.	3.6%	1.2%
		Westbound	125 ft.	5.5%	1.0%
"	Marysville, Penna.	Eastbound	250 ft.	2.5%	1.2%
		Westbound	225 ft.	2.0%	1.2%
"	Alexandria, Va.	Eastbound	100 ft.	2.5%	1.0%
		Westbound	100 ft.	2.5%	1.0%
"	Greenville, N. J.	Tidewater	50 ft.	2.5%	1.0%

Of the above yards, the most satisfactory in operation are the Elkhart yards and the Collinwood yards of the L. S. & M. S. Ry., the Harrisburg No. 4, and the Enola yard of the Pennsylvania R. R. Each of these have momentum grades of 3.5 per cent. to 5.5 per cent. and are stated to be entirely satisfactory by the local division and general officers. In making this statement it is only fair to say that this conclusion was formed by the writer prior to his entering the service of the L. S. & M. S. Ry.

The Clearing yard, more generally known as the "Stickney" yard, and the Alexandria yard, were not in operation when examined by the writer.

There are other extensive and well tried yards in the United States, which the writer has not had opportunity to examine.

The New York Central's yards at DeWitt and Albany, the P., C., C. & St. L. Ry. yards at Columbus, Ohio, and the Pitcairn yards, near Pittsburgh, and the Hazelton yards of the Pittsburg &

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*Combination of various grades, averaging about this ratio.

Lake Erie Railroad, near Youngstown, Ohio, have not been personally examined, although each of them is an important point and would afford much information. Verbal advices from the operating or engineering authorities at each of these points, however, have been received which confirm the conclusions shown in the preceding tabulation of advisable grades.

THE GENERAL RELATION OF THE COMPONENT PARTS OF A YARD SYSTEM.

It need hardly be said that the relative physical position of the receiving yard, the separating yard and the forwarding yard should be such that the movement of cars will be forward toward destination. This calls for a tract of land from one to four or five miles in length, which is often impracticable to secure at a justifiable price. This rule can be violated apparently with impunity, and still by good design in the yard arrangement, not appreciably delay traffic; just where to draw the line in a dicision is very hard to say. For instance, the New Orleans Terminal Yard of the Illinois Central Railroad at Harahan, Louisiana, is placed substantially at right angles to the main track of the Illinois Central and Yazoo and Mississippi Valley Railroads. It is stated by the present general officers of those companies to be satisfactory in operation in spite of the fact that when a train has gone through the yard it is physically no farther along toward destination than when it entered the yard. At Collinwood, Ohio, are the two gravity yards of the Lake Shore & Michigan Southern Railway, one for east bound traffic, one for west bound traffic. Both yards are constructed for moving cars directly to the west owing to the natural slope of the original surface being descendent to the west. No appreciable delay is experienced in handling the heavy east bound traffic in a westward yard movement at this point.

In the smaller yards, operated by the push and pull method, the local conditions almost absolutely control the relative location of the different parts and no other general rule can be given than the one above, and the discussion under the sub-heading of "ladder leads." The skill with which the general principles of yard design are adapted to a given point, determines the efficiency of a yard. All the demands of a fairly busy point can be met by a yard of eight body tracks and the auxiliary facilities under good arrangement.

Plates 2 and 3 show the arrangement of drilling lead and body tracks of these simpler types of yards, to be embodied in the design of a small yard for a particular point. These give eight tracks as the advisable number on a single drill track. Such an arrangement makes one body track a receiving track, another body track the forwarding track upon which the new train is made up, and assigns the other six tracks for the classification work. No attempt has been made to more than show the units of the advisable arrangement for classifying; this work is the most important of the yard, and if it is well provided for, there need be no difficulty in adding the car repair tracks, caboose tracks and other facilities needed. The amount of elaboration of these units, the addition of other tracks at either end to act as receiving and forwarding tracks, and other increased construction, all depends on the amount of business anticipated.

THE AUXILIARY FACILITIES REQUIRED IN A TERMINAL YARD, AND EQUIPMENT FOR CONVENIENT WORKING.

The special work to be done in terminal yards is more or less similar in all localities. It consists of items a follows:

The repair of cars found to be defective. This work may or may not require the contents of the car to be transferred. The proportion requiring transfer would probably not exceed one-quarter of the total number of bad order cars.

The adjustment of shifted loads. It is difficult to load and bind certain classes of freight to hold to position, and such loads, when shifted, must be replaced for safe forwarding. This is particularly true of lumber, which frequently shifts. It is not necessary to transfer to another car such loads, unless damage has resulted to the car. Shifted loads of lumber on plain flats can be squared up by pushing against the shifted lumber a "squaring car."

The rearranging of improperly loaded cars into proper cars.

The transferring of contents of cars, to save per diem or penalty.

The transferring of contents of cars, to utilize equipment to greater advantage.

The consolidating of partial car-load lots to secure greater tonnage.

The transferring of L. C. L. freight to suit destination.

The transferring of special products to permit of classification and distribution according to destination as thereby determined.

This work of transferring, rearranging, and consolidating freight is an attendant evil in all terminals; it cannot be overlooked except at distinct disadvantage. Properly handled, it favorably affects the tonnage showing, the time showing, and the economy of operation. For its convenience should be furnished a sufficient number of parallel tracks, with a covered transfer platform at some central point, and individual platforms also between each two tracks. The object of these platforms is to save spotting the cars and to permit free movements of truckmen up and down the lines of cars; the covered platform is to permit occasional storage of car contents temporarily in readiness for final reloading. At the end of the covered platform should be built sufficient warehousing to hold freight without bills, "over" freight, freight not completely loaded at the close of work at night, gang-planks, trucks, and for the conveniences for the truckmen, check clerks and bill clerks. A transfer crane is needed for lifting heavy loads for re-adjustment or transfer.

THE ICING PLANT.

During all the year in tropical or semi-tropical climates, and during the bulk of the year in cooler climates, perishable freight in transit needs re-icing. In some cases this freight moves in solid train lots, but usually it comes mixed in with other cars, or with other freight at the rear of the train to fill out the train loading. For solid trains the road crew should be able to take the train direct to the icing plant without stopping in or running through the receiving yard. For partial train lots, the movement must be over the hump of the separating yard, this being the quickest way of separating the cars; for partial train lots, with the perishable freight bunched behind the engine, direct and quick access from the outlet end of the receiving yard to the icing plant is essential, and in turn convenient outlet from the icing plant to the forwarding yard is needed. The icing plant itself must be equipped with a convenient machinery room for preparing the ice and with overhead runway platforms alongside the icing tracks to permit rapid work.

It is not wise to attempt the icing of more than twenty-five cars at a time on each track, owing to the melting of ice in long hauls in trucks. Accordingly, the ideal arrangement is for platforms one thousand feet long, with an equal length of icing track beyond each end, so a lot of twenty-five cars, iced can be moved on ahead, and a second lot be quickly brought up to the platforms from the rear.

The dimensions of the house itself are controlled by the numbers of tons storage capacity required. If icing tracks and platforms are needed on one side only, and the other side for filling the house in the winter, or loading cars for shipment to other points, a width of about 60 feet is advisable. If the house is to have icing tracks on each side, it should be of greater width, to secure proportionate storage capacity. Whatever the width may be, the house should be built in units or pockets that can be added to as greater capacity is required; the central unit of the house should be the machinery room where all the ice breaking is done, and, to and from which all movement to the outside are made. Such an arrangement for working minimizes the melting of ice, and expedites the icing of the cars.

THE LIGHTING OF A YARD FOR NIGHT OPERATION.

Yard work is dangerous, difficult and slow, during the hours of darkness and during fog. Electric lights are frequently used for yard illumination, and the switchmen supplement these by leaving a lantern on the ground opposite the end of the last car on each track. The electric lights, as ordinarily used, are not effective, and the cars are handled slowly as a result. The defect of these lights is due to their dimness, the lack of sufficient number, and their ineffective placing.

To overcome this trouble on the humps and ladders, Mr. M. E.

Shire, Engineer in Charge, of the "Clearing Yards," Chicago, has developed a device like the reflector of a locomotive headlight; each light is equipped with one of these, and it is placed so the rays of light are directed toward the important channels of the work. The classification yards are most in need of such a lighting arrangement, and as there are no reverse movements in this yard, not even the slight disadvantage of lines of clear light shining at times in the faces of the switchmen is experienced. While all portions of the yard system should work smoothly and without delay, the work is concentrated at the entrances and on the ladder leads of the classification yard as all cars must enter the yard over a single throat track and go to their respective destinations by way of one of the ladder leads. Furthermore, the momentum required to start the cars and carry them well into the classification yard must be imparted by the grade of the throat track and ladder leads. Consequently, the maximum speed of the car occurs in its movement over the ladders, and if this speed is checked by the brakes

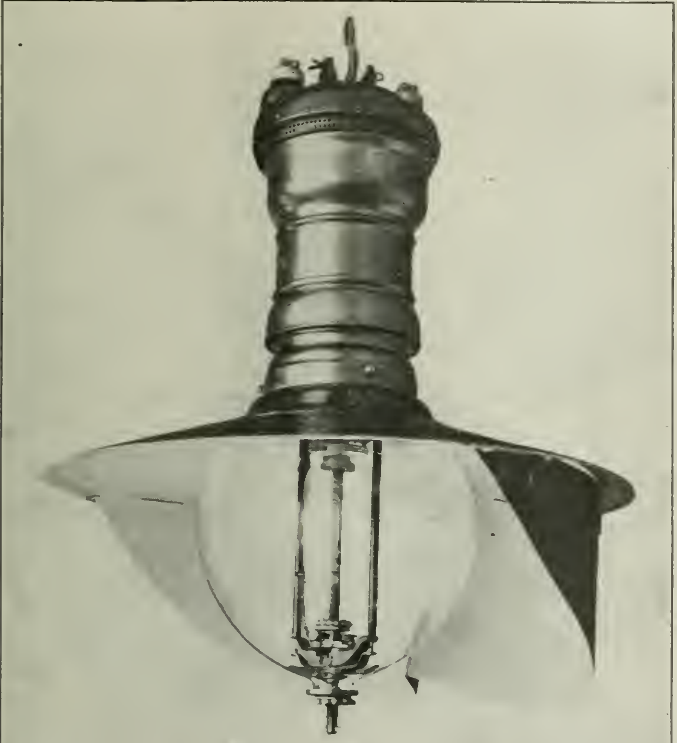

PLATE 5.—FRONT VIEW OF ALTERNATING CURRENT ENCLOSED ARC LAMP WITH REFLECTOR FOR DIRECTING RAYS OF LIGHT FORWARD AND DOWNWARD

by the rider, because he cannot see the car ahead of him clearly enough to judge of its relative position and speed, the capacity of the entire yard is thereby affected. There are no yards as far as observed where this lack of sufficient light does not lessen the operating capacity during the hours of darkness.

For lighting the ladder leads of the classification yard, one or more of these lights with reflectors is placed at proper intervals from the hump to the ladder end, on poles or on steel bridging similar to the bridging frequently used for signals; the height must be sufficient to avoid casting serious shadows from one car to another, and the reflectors properly trained to throw the rays of light where needed. In the body of the classification yard these lights are needed in greater quantity, and arranged to sweep the yard at different angles; on the outlet ladders, and in the other yards of the system, this type of reflector is undesirable as the switching is equally backward and forward in direction, and movement toward the lights would be blinded by its rays. Accordingly,

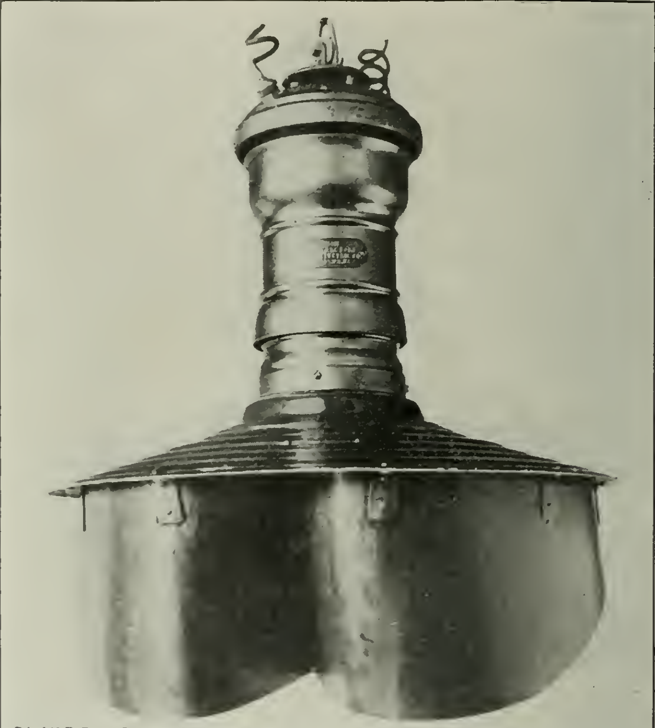

PLATE 5.— REAR VIEW OF DIRECT CURRENT LUMINOUS AND ALTERNATING CURRENT ARC LAMPS WITH REFLECTORS FOR DIRECTING RAYS OF LIGHT FORWARD AND DOWNWARD.

the effective arrangement in these places is a general diffused light reflected downward only.

For the Dupo yard of the Gould System there has been developed under the writer's direction, a similar system of conserving and reflecting the rays of light to the points where they are needed Based upon this idea, a similar type of reflector was developed by the General Electric Company, in place of the locomotive headlight type, and the reflecting surface instead of being of silver plate or nickel plate, was of porcelain enamel on thin sheet steel. For the ladder leads and the portions of the classifying yards where the light rays are directed forward in one way only, there was developed the type of reflector shown in plate 5, and for the parts of the yard where only a generally diffused illumination was needed, the skirt was omitted from this pattern. The lights were carried on systems of general current bearing lines of not greater than 440 volts, so arranged that the breakage of a single line would plunge only one part of a yard in darkness. This scheme makes its first cost, maintenance and repair economical and minimizes both the danger to employees, and the amount of interruption to work due to breakage of wire lines. The details of the lighting arrangement constitute in themselves material sufficient for a separate report, and need not be further elaborated here. The writer has not seen any adequate lighting arrangement in use in any yard so far examined, and regards this detail as one of distinct importance.

DON'TS.

A discreet engineer tries to perfect his methods of design and construction, by noting other men's work, profiting by the lessons to be learned both from successful portions, and from the unsuccessful portions. For this reason, it may be well to insert cautionary words here to show what points in yards now operated, have proven clearly undesirable, as an emphasis for the suggestions as to good practice so far given.

Do not attempt to design any yard until thorough study has been made of the business to be handled by that yard; then make the best guess possible at the amount and character of business that can be anticipated for the future. Work out a plan for handling this future business; for the present arrangement, plan to build the proper proportion of the final plan, so far as possible on the lines of the final scheme. Do not limit the land purchases so as to interfere with a good working arrangement. Do not attempt to adopt types and methods of design for comparatively small amounts of business, that are successful only with heavy business. For instance, there is no justification for building a hump yard to handle the general merchandise, lumber, grain and coal traffic of the ordinary division station, or ordinary terminal station. The hump yards that have been built at a number of points for comparatively small business, are so far as observed, costly and unsatisfactorily in operation and the best operating men agree that the hump yard type is as inadvisable for moderate business as it is essential for heavy business.

Do not neglect the proper lighting of a yard for night work until the yard is under construction or later. The best location for the necessary light carrying poles should be provided by spreading the tracks to admit them without peril to trainmen at work. Note carefully the methods of conserving and directing the rays of light outlined earlier in this article, and adapt them to each portion of the proposed yard to suit the respective switching movement.

Do not permit curvature in excess of eight degrees per station in any important parts of the yard; do not introduce any avoidable curvature even within this limit; do not fail to compensate for curvature in hump and gravity yards, in the portion where gravity is used as motive power.

Do not fail to arrange for surface drainage.

Do not fail to provide sufficient spacing of tracks for convenience in giving and seeing signals, and throwing switches, and the other work of the yard.

Do not fail to provide sufficient drilling tracks so that switch engines can work freely without friction or interference with each other, or with incoming or outgoing trains.

Do not, even in the smallest yard, attempt to have the car repairs made, or cabooses or wrecking outfit stored, on tracks in the body of the yard,—put them on tracks of their own outside.

Do not lightly decide where the scale shall be placed. Give this item the most careful thought.

Do not make the classification tracks too long, as delay and extra expense in switching is thereby occasioned.

Do not couple too many body tracks to a single ladder.

Do not forget that a yard should be as elastic as possible for present use, and so design that future enlargement will be on a harmonious scheme.

IN CONCLUSION.

There is submitted as plate I, outline drawing of the terminal yard designed by the writer, for the East St. Louis territory of the Missouri Pacific Railway, the St. Louis, Iron Mountain & Southern Railway, the Cotton Belt Railway, and for the incidental use of the Wabash Railroad. This yard is now under construction, practically all the grading being complete, and a considerable portion of the track laid. Portions of the yard have been in use since about October 1st, 1905. About one-half the trackage called for on this plan is to be built as the first installment of the terminal, the balance being provision for the future.

This plan is submitted as the writer's idea of the application of the principles of yard design, for the conditions prevailing in the East St. Louis territory.

It is a matter of regret that the plan submitted for the Buffalo terminals of the New York Central Lines cannot be shown.

This plan has been approved by the operating officers of each Company, but as it is still under consideration by the executive officers, it is improper to publish it just now.

It seems unwise to develop a so-called typical yard plan for insertion herein because no two yards are alike. The lay of the ground, the character and amount of the traffic, the relative position of connecting lines, the ruling grades of the avenues for forward movement, all affect the design that can properly be used, and a design worked out in the best good faith for one situation, or for an assumed situation might be not only uninstructive but misleading if applied to other points.

The general matter of railway terminals is one of importance. The expense of handling traffic through illy arranged yards is not only heavy in the direct cost for labor and for damages to contents of cars in reswitching, but indirectly in the lessened income from the cars themselves, and from the loss of traffic that results from delay and embargo. The writer has knowledge of one case where under as favorable operating methods as the situation permitted and during a time when business was moderate a forward movement of about two and one-half miles was made in 46 hours on an average during the period investigated, and many cars were lost track of in the confusion of movements that was unavoidable. This is not believed to be an extreme case. The cost of a trackage scheme in this particular instance that would have been adapted to the work of switching would not have been excessive and the net saving would have been very great. It not infrequently occurs that the major portion of a yard is well arranged, but the switching is interfered with by improperly placed switches or a bad ladder scheme or drilling tracks that are difficult to use; under such conditions a small investment in rearrangement may make the yard serviceable and economical in use.

In the improvement of such existing yards, or the design of new yards, there is one suggestion the writer respectfully makes to those who may undertake such work; that is, study thoroughly the work that must be done to arrange traffic for forward movement, and then arrange tracks so this work can be done in the simplest, easiest way by direct movements, free from friction. Any track scheme that will not stand thorough analysis on this basis may well be regarded as suspicious; any scheme that invites derailment, or that necessitates large forces of men when business is small, or that makes reswitching continually necessary, or that calls for elaborate construction where simple construction is sufficient, or that fails to provide for the auxiliary work, of a yard, should be avoided.

To learn from the good features and the less desirable features of existing yards, those lessons needed in the design of a new terminal, requires thorough investigation on the ground; not an investigation of a few hours or a day during favorable weather, but days and nights of watching the work, during good weather and bad. Time is often hard to spare, but there are few lines of work where thoroughness is more essential than in terminal design.

IN MEMORIAM.

A. W. FIERO, M. W. S. E.

July 28, 1906.

Albert Winfield Fiero was born in Battle Creek, Michigan, on January 29, 1849. His birthplace was on a farm lying in the suburbs of that town, on which his boyhood was passed, while he attended the schools of the locality until he was eighteen years old, when he obtained employment under local surveyors for a couple of years. In July, 1869, he was given an appointment on the civil engineering corps of the Peninsular, afterwards, Southern Michigan Railway Company, then making preliminary surveys through Michigan. He remained with that company until July, 1873, when he was appointed an assistant engineer with the Chicago & Illinois River R. R. Co., under Chief Engineer J. O. Hudnutt.

Upon leaving the service of the Peninsular Ry. Co., its President, S. D. Dibble, gave him a letter in which he stated, "You gave good satisfaction as to ability and strict devotion to your duty."

Again, when he left the service of the Chicago & Illinois River Company, Chief Engineer Hudnutt, under date of May 28, 1875, wrote, "It gives me great pleasure to bear withness to his many sterling qualities——I can most cheerfully endorse and commend his diligence, fidelity and honor."

He afterwards entered the serviceof the Chicago & Alton Railroad Company, as assistant engineer, while N. F. Booth was its chief engineer, and that gentleman wrote in 1876, "I regard him a very competent and worthy young man."

These testimonials record that Mr. Fiero, from the very outset of his career, manifested those high qualities which later helped him to success, and which won and retained for him the confidence and esteem of a very wide acquaintance.

The production of Bessemer steel rails in the west, and their use by railways of that section, attracted his attention, and he entered the employ of the Vulcan Steel Company in their Bessemer rail plant at St. Louis, Mo., so as to familiarize himself with the details of steel rail manufacture, and later was appointed the rail inspector for the Chicago & Alton Railroad by his former Chief, Mr. Booth, in which position he remained for a number of years. Subsequently he arranged to represent other railway companies in the same capacity, making his home and headquarters in Joliet, Ill.

In that city on May 5, 1881, he married Miss Florence E. Carpenter, who, with a son, Albert Conro, and a daughter, Emelie Louise Fiero, survive him.

In 1889, Mr. Fiero became a member of the firm of Robt. W. Hunt & Co., which connection continued until his death, on July 28, 1906, after a short illness.

Mr. Fiero was active in Masonry, and had attained the thirty-second degree. He was a member of the Protestant Episcopalian church, and for many years was on the vestry of Christ Church, Joliet, Ill.

He was a member of the American Institute of Mining Engineers, American Railway Engineering & Maintenance of Way Association, The American Society of Testing Materials, and the Western Society of Engineers. He took great interest in the work of the latter organization, and was one of its earlier members, having joined in June 1886.

He was a member of the Union League, Midlothian Country Club, Engineers Club, Chicago, and of the Engineers Club, New York.

Few men had a more extensive acquaintance, which was not only among the railway engineering profession, but also embraced active business men in many interests, and in all parts of America, by whom he was universally respected.

ROBERT W. HUNT.
(Signed) ROBERT FORSYTH.
C. W. HOTCHKISS.

THE ECONOMIC VALUE OF EXPERIMENT STATION WORK.

The Engineering Experiment Station, of the University of Illinois, has recently issued, bound together in book form, the first eight bulletins and the first two circulars published by the Experiment Station. The first of these bulletins was published in September, 1904, and the other publications followed at intervals during the succeeding two years. The book, which has just been issued, combines these publications in a form convenient for preservation.

The subjects considered in the publications, contained in this book, include:

Tests of Reinforced Concrete Beams.
Investigation of High Speed Tool Steel.
Drainage of Earth Roads.
Resistance of Tubes to Collapse.
Holding Power of Railroad Spikes.
Fuel Tests with Illinois Coal.

In all of these live subjects, a great amount of original and valuable investigation has been made by competent investigators, and the results obtained, particularly in the investigation of the properties of "Reinforced Concrete Beams" and the "Fuel Tests with Illinois Coal," are considered, at the present time, the standard publications on these subjects.

Experiment Stations designed to give results of immediate practical value to agriculture have been maintained for many years by state and federal aid, and it may be conservatively said that the financial benefit resulting from the work of these experiment stations repays annually ten-fold all moneys expended on them by state and nation from the beginning.

As the possibilities of new principles in engineering and improved methods of manufacture are unlimited, and as the value of the output of manufactured goods greatly exceeds the value of the products of the farms of the country, it is a matter of surprise that engineers and manufacturers who pride themselves upon their enterprise and scientific insight should allow the farmers to outstrip them in initiative and appreciation of experiment station work.

The idea of an *Engineering Experiment Station* is, we believe, original with the *University of Illinois*, and the results so far attained, as well as the subjects now under investigation, are demonstrating that the possible advantages to be derived from an *Engineering* Experiment Station are equal to the benefits obtained from an experiment station of any other kind, and it is to be hoped that the sucess of this venture, at the University of Illinois, will lead to the establishment of Engineering Experiment Stations in many other Technical Institutions, and that their value will be so recognized by State and Federal Government that their endowment and support will be as liberal as is that now given to the Agricultural Experiment Stations.

W. L. ABBOTT, President W. S. E.

PROCEEDINGS OF THE SOCIETY.

Minutes of the Annual Meetings.

The 37th Annual Meeting (No. 593) of the Western Society of Engineers, with the Annual Dinner, was held on the evening of January 8, 1907, in the rooms of the Mid-Day Club in the First National Bank Building.

A short session of the Board of Direction received the report of the Judges of Election, which showed who were elected officers for the year 1907. A short meeting of the Society was held, when the announcement was made from the Board of Direction of the result of the election, as follows:

W. L. Abbott, President of the Society for 1907.
Andrews Allen, First Vice President of the Society for 1907.
E. N. Layfield, Second Vice President of the Society for 1907.
A. N. Talbot, Third Vice President of the Society for 1907.
A. Reichmann, Treasurer of the Society for 1907.
W. C. Armstrong, Trustee of the Society for 1907-8-9.

They then adjourned to the dining room. After the dinner was finished, the retiring President, Mr. Arnold, made a brief address, stating the progress and work of the Society for the past year of 1906. He then introduced President-elect Abbott, and turned the Society over to his care for the year 1907. Mr. Abbott responded in a brief but pleasant and interesting manner, and then introduced Mr. Willard A. Smith as Toastmaster of the evening. Toastmaster Smith, after some interesting remarks along the lines of the general subject of engineering and its relation to other interests and professions, introduced Mr. Julius Stern, a lawyer and associate member of the Society, who made some thoughtful and also humorous allusions to the "Parallels" between the engineering and the legal professions. Before closing he became more serious and made a sober, earnest plea on behalf of a proper feeling on the part of engineers toward their obligations to the city and community in which they live.

Mr. Finley was afterward called upon, with a suitable introduction by the Toastmaster, who mentioned some of his earlier experiences in the engineering profession.

Mr. Arnold then proceeded to give a comprehensive statement as to the present condition of the electrification of railway transportation as exemplified in New York and elsewhere. His remarks were illustrated by many lantern slides, and were appreciated by the audience.

Something over 100 members and guests were present; the meeting adjourned about 11 p. m.

Minutes of the Extra Meeting, January 23, 1907.

An extra meeting of the Society (No. 595) was held in the Society rooms, Wednesday evening, January 23rd, 1907.

The meeting was called to order about 8:15 p. m., with President Abbott in the Chair, and about 80 members and guests present.

There was no business to bring before the Society, so Mr. H. M. North, Asst. Engr. of Construction, L. S. & M. S. Ry., Cleveland, Ohio, was introduced as the speaker for the evening. His paper, "*The Theory of the Design of Railway Freight Terminals,*" which had been printed and sent out in advance, was not read by the author, but by the aid of two large blue-prints of the Freight Terminals at Dupo, Ill., near St. Louis, and at Gardenville, near Buffalo, N. Y., Mr. North showed clearly the requirements in the design of a *Freight Terminal.* The talk was substantially the printed paper, except that it was presented in a more informal manner, with constant explanatory reference to the plans exhibited.

Some little discussion following the paper, and on motion, a vote of thanks was tendered Mr. North, for his very interesting presentation of the subject. The meeting adjourned about 10:10 p. m.

Minutes of the Regular Meeting, February 6th, 1907.

A regular meeting of the Society (No. 596) was held in the Society rooms, Wednesday, February 6th, 1907.

The meeting was called to order about 8:10 p. m., with President Abbott in the Chair, and about 30 members and guests present. The minutes of the preceding meeting were read and approved.

The Secretary reported from the Board of Direction, that at their meeting of January 5th the following were elected into membership:

	Grade.
Lee Jutton, Chicago	Active
Albert F. Wright, Chicago	Active
Paul A. Degener, Chicago	Active
George L. Sawyer, Lewiston, Idaho	Active
Harold H. Clark, Chicago	Active
Bert A. Gayman, Chicago	Active
John H. D. Petersen, Chicago	Active
Axel G. Johnson Rapp, Chicago	Active
James Hyslop, Harvey, Ill	Active
Edward N. Lake, Chicago	Active
Albert H. Aldinger, Chicago	Transfer from Junior to Active
Charles C. Hotchkiss, Chicago	Junior
William J. Miskella, Chicago	Junior
Edwin H. Smythe, Chicago	Active
H. B. Otis, Chicago	Active
V. Y. Davoud, Chicago	Junior
Walter F. Reichardt, Little Rock, Ark	Transfer from Junior to Active
J. L. Hecht, Chicago	Active
H. R. Armeling, Minneapolis, Minn	Junior
M. L. Enger, Minneapolis, Minn	Junior
Harvey B. Fleming, Chicago	Active

Also, that at the meeting of February 5th the following were elected into membership:

	Grade.
Francis W. Lawrence, Madison, Wis	Associate
William H. Carden, Oglesby, Ill	Junior
M. B. Stewart, Chihuahua, Mexico	Transfer from Junior to Active
F. E. Lamphere, Chicago	Junior
W. Van R. Whitall, Chicago	Associate
Andrew W. Woodman, Chicago	Active
Hugo Schmidt, Chicago	Transfer from Junior to Active
Vene D. Fry, South Pittsburg, Tenn	Junior
John L. Hall, New York City	Transfer from Associate to Active
Henry Kreisinger, St. Louis, Mo	Active
Louis E. Williams, Chicago	Active
William B. Storey, Jr., Chicago	Active

Also, that applications for membership had been received from:

Edwin H. Cheney, Chicago.
A. D. Page, Chicago.
T. R. Minert, Chicago.
Frank N. Savage, Chicago.
Jas. Guy Huff, Nashville, Tenn.

A resolution was introduced, requesting the President to appoint committees for the preparation of memorials for publication in the Journal, W. S. E., of our late members, Mr. O. B. Green, who died December 30th, 1906, and Mr. A. R. Eldridge, who died January 17th, 1907. The President appointed for these Committees, Messrs. Isham Randolph, Fred Davis and G. A. M. Liljencrantz, for the memorial of Mr. Green; and Messrs. J. E. Roemheld, L. J. Hotchkiss, H. N. Elmer and E. N. Layfield, for the memorial of Mr. Eldridge.

There being no other business to bring before the Society, President Abbott, after speaking of the wealth to the State of her natural resources, which are now being investigated and reported on by the State Geological Survey, introduced the speaker of the evening, Dr. H. F. Bain, Director of the Survey.

Dr. Bain did not read his paper, which had been printed and sent out in advance, but gave the substance of it, *"The Work of the State Geological Survey,"* in an informal address, which was illustrated by some large maps, hung up for the purpose.

Discussion followed from Messrs. W. L. Abbott, U. S. Grant, W. W. Atwood, George S. Rice, A. Bement and H. F. Bain.

A resolution was introduced by Mr Layfield, that the Secretary prepare and forward a suitable memorial or petition to the State Legislature, now in session, that it make a liberal appropriation to continue and enlarge the work of the State Geological Survey. This resolution was carried, and as the Secretary asked that a committee be appointed to assist in the preparation of such a memorial, the President appointed Messrs. L. E. Cooley, Robert W. Hunt and A. Bement as such committee.

The meeting adjourned about 9:50 p. m.

Minutes of Extra Meeting, February 20th, 1907.

An extra meeting of the Society (No. 598) was held in the Society Rooms Wednesday evening, January 20th, 1907.

The meeting was called to order about 8:20 p. m., with President Abbott in the Chair and about 30 members and guests present. As there was no business to bring before the Society, the Chairman introduced Mr. R. S. Kellogg, Forest Inspector of the U. S. Forest Service, Washington, D. C., who presented his paper with some running comments on *"Some Problems of Wood Utilization in the United States."* This paper had been printed and sent out in advance. Two large charts were hung up, which served to further elucidate the subject. Discussion followed from Messrs. W. L. Abbott, Lawry, Morse and J. H. Warder.

After a motion to return a vote of thanks to Mr. Kellogg for his interesting and valuable address, the meeting adjourned about 9:50 p. m.

ELECTRICAL SECTION.

Minutes of Meeting, January 11th, 1907.

The annual (and 21st) meeting of the Electrical Section (No. 594 of the Society) was held the evening of Friday, January 11th, 1907.

The meeting was called to order about 8:15 p. m., with Vice-Chairman P. Junkersfeld in the Chair, and about 60 members and guests present.

The Secretary explained that this was the date for the election of new members of the Executive Committee and who had been put in nomination at the preceding meeting. The ballots were then taken up and canvassed by Messrs. Schuchardt, Price and Warder; and the results announced as follows:

For Chairman of the Electrical Section for 1907, Mr. C. A. S. Howlett.

For Vice-Chairman of the Electrical Section for 1907, Mr. D. W. Roper.

For member of Executive Committee (to serve three years), Mr. K. B. Miller.

Mr. Howlett was then introduced and assumed the chair. There being no other business to bring before the Section, Mr. Ernest S. Smith was introduced, who read his paper, with lantern slide illustrations, on *"The Development and Operation of a Large Electric Transmission and Conversion System."* Discussion followed from Messrs. D. W. Roper, H. R. King, C. A. S. Howlett, E. F. Bracken, P. Junkersfeld and J. H. Warder.

The meeting adjourned about 10:30 p. m.

MINUTES OF THE MEETING, February 15th, 1907.

The 22nd meeting of the Electrical Section (No. 597 of the Society) was held Friday evening, February 15th, 1907.

The meeting was called to order about 8.35 p. m. with Chairman C. A. S. Howlett presiding, and about 30 members and guests present.

The minutes of the 21st meeting of the Section, held January 11th, 1907, were read and approved. The Chairman then introduced Mr. H. M. Biebel of the Western Electric Company, who read his paper on *Direct Current Compensators for Balancing Electric Circuits.* This paper was illustrated by a number of lantern slides of explanatory diagrams, and of the appearance and construction of the machines.

Discussion followed from Messrs. Howlett, Pratt, Atkins, Kline, Roe, Roper and Hellmund.

The meeting adjourned about 10:10 p. m. J. H. WARDER,
Secretary.

ADDRESS OF RETIRING PRESIDENT, BION J. ARNOLD, AT ANNUAL MEETING JAN'Y. 8, 1907.

Gentlemen, Members of the Western Society of Engineers, and Friends.

I take pleasure in greeting you again on the anniversary of my election as your President, and I wish to thank the other officers, as well as the members of the Society, for their cordial support during the year.

It now falls to me to give a brief statement of some matters pertaining to the welfare of the Society for the past year.

Our membership has increased in a satisfactory way, the net gain for the year 1906 being 69, and the total membership is now 925. There will be some losses from this number, but the new applications in hand and recently voted upon will probably balance such losses. We are called upon to lament the loss of six active members of the Society, the last being the venerable *Mr. O. B. Green,* for so many years associated with us, who passed out December 30th. The first loss of the year was *Mr. H. W. Parkhurst,* who died April 7th. He was known to many of us in his position as Past President of the Society. The others who have been taken from us are, *Mr. John Saltar, Jr., of Philadelphia,* July 11th; *Mr. A. W. Fiero, of Chicago,* July 28th; *Mr. F. P. Dobson, El Paso, Texas,* August 25th; and *Mr. A. V. Abbott, of New York,* December 1st.

The Junior membership has been increased by 32 this past year, and now has reached the creditable number of 126. It would be well, however, as has been suggested in previous years by one of our Past Presidents, if there could be a greater increase in the Associate list. There should be in this territory a large number of men available for Associate grade because of their interest in engineering matters, whether as contractors or material men, and it would be well if some effort were made to induce them to come into the Society.

The finances of the Society have been carefully conserved by the Board of Direction. All moneys have been paid out on vouchers properly scrutinized and endorsed, and it is believed that all expenditures have been judicious ones. A small surplus is gradually being accumulated, which is invested from time to time in interest-bearing securities. Notwithstanding these facts, and feeling the great necessity for enlargement of our quarters, and perhaps a more aggressive policy in our management, the Board of Direction has given careful consideration as to how the income might be increased. Meetings have been held where the advice and counsel of the Past Presidents of the Society have been asked; circulars have been sent out to our members stating the present condition of affairs, and what was the desire of the Board of Direction, and the replies from all quarters were used as a further element in the consideration of the question. The final result is known to most of you, viz., that a Resolution was introduced at one of the regular meetings, as prescribed by the By-laws, to amend the By-laws in the matter of "Fees and Dues." This increase obviously falls most heavily upon the resident membership, as they receive the greater benefit from the library and meetings of the Society. This amendment was submitted to the Active Members of the Society for vote, by letter ballot, with a result that over 77 per cent. of the votes sent in approved of the increase of fees and dues as embodied in the Resolution. It is possible that some of our members may feel that the increase is a little hard on them, and may offer their resignations, so the net result to the Society is a question that time only can answer. It is estimated by the Finance Committee that this increase in fees and dues should add about $2,000 to our income. This amount will be of great assistance in paying the increased rent that will be necessary should we move into larger or more desirable quarters. Our present accommodations are lamentably crowded and insufficient for our needs—particularly for the library and reading room—but the meeting room is also defective in ventilation and acoustic properties.

The Publication Committee and the Secretary are to be congratulated upon the meetings and papers presented, and also upon the Journal as it is published. Twenty-nine called meetings were held last year, as well as an extra meeting, which was a Ladies' Night, when the Society and its guests were entertained by Mr. Karner with a description of *Panama, Past and Present.* At 28 of these meetings technical papers were presented, most of which have been published the past year in our Journal, although there are some left over as a supply for the new year. A list of these meetings, and the papers presented, is given in full in the annual report of the Secretary.

Our Library is attracting more and more attention from our members and the public, who have free access to the books and papers which it contains. The number of books in the Library at the end of last year is a trifle over 6,100, and the accessions for the year 1906 were over 500. Of this number, over 300 were bound books coming to us in exchange for our Journal from sister societies, or were gifts from our members or book publishers. The book publishers are recognizing the value of our Library and the Journal by their more liberal gifts of technical publications, to be reviewed in the pages of our Journal. This necessitates the kindly co-operation of the members of the Society in preparing these reviews, and it is hoped that a still greater interest may be shown in this work. The reviewing of a book is of greater benefit to the one who writes the review than anyone else, and there should be no hesitation in accepting the call to prepare such a review, which accrues to the benefit of the individual called upon.

One important matter has been taken in hand by the Library Committee this year, and that is the preparation of a list of our books. It is hoped that this present year the list may be put in pamphlet form, and thus made available for the use of our members. This, and other matters pertaining to the Library, will be found in detail in the Librarian's report, to be published in the Journal.

It is now my pleasant duty to announce the election of Mr. W. L. Abbott as President of the Western Society of Engineers, who has done excellent work for the Society during the past, and has well earned the honor you have conferred upon him.

ADDRESS OF THE NEW PRESIDENT, W. L. ABBOTT.

Mr. Toastmaster, and Members of the Society, Friends.

Experience has taught me that the uncertainties of the fortunes of elections make it unadvisable for a candidate to presume upon his success to the extent of preparing an inaugural address before the ballots are counted, or if, for want of sufficient time between the count and inauguration, the address must be prepared beforehand, it should not have the appearance of having had such preparation, and the observance of the appearance clause of this rule, I am told, has been the characteristic feature of the inaugural addresses before the society during past years. It is therefore incumbent upon me to maintain the precedent.

Again there is not a great deal for the new president to say except to tell what he is going to do, but as boasting is more becoming to him that putteth off the armor than to him that girdeth it on, I am again prevented from delivering such an address as I should like to.

But while recognizing my limitations and bowing to the inevitable, neither convention nor circumstances may prevent me from congratulating our retiring president and the society upon the very successful year we have just passed. A year filled with all good things, good president and good papers; good fellowship and good finances; a good increase of good members and good constructive legislation for the future. Surely, if the Society ever was in a condition to be entrusted to non-experts, it is now.

Permit me to say a word further about the good things we have received during the past year. A year ago the Society honored itself and honored Mr. B. J. Arnold, by selecting him for its president. Owing, however, to the great demands of his private business upon his time, he was unavoidably absent from the city a great deal, and particularly so upon our meeting nights. Wishing, therefore, to make some slight amends to the Society for the loss it had endured through not having its President present at all meetings, Mr. Arnold has written a letter which I will read, because he asked me not to do so. The letter is as follows:

Chicago, January 5, 1907.

Board of Direction, Western Society of Engineers, Monadnock Bldg., Chicago.

GENTLEMEN: Desiring to be instrumental in furthering the interests of the Society, over which I have had the honor to preside for the past year, in all practical ways, and feeling that I cannot do so to any better advantage at the present time, than by contributing to its material resources, I beg leave to tender herewith the sum of one thousand dollars ($1,000), to be used for the benefit of the Society, as its Board of Direction may elect. This gift is made without conditions, as I desire the members of the Board of Direction to be perfectly free to determine from time to time how the income from this money, or the entire amount, may be used for the best intrests of the membership.

Wishing the Society continued usefulness and growing prosperity, I am,

Yours sincerely,

(Signed) BION J. ARNOLD.

Accompanying the letter, was Mr. Arnold's check for $1,000, which was promptly and gratefully accepted by the Board of Direction for the Society I will now ask you to rise and give three cheers for our retiring President, Mr. B. J. Arnold. (Three cheers and a tiger.)

While it is not permitted to me to review the past nor boast of the present, I may at least conjure up a pipe dream of the future.

Let us start with the map of the middle and western west as a background and with Chicago strategically situated. Note the energy of its millions of people, and the activity of its billions of capital; see the broad fertile farms of constantly increasing productiveness providing the greatest market in the world for manufactured goods; see the great railways congested with traffic; the public works, factories and other industries in operation, building or projected.

Listen to the call for trained engineers to direct these industries, and in response to the call, see the halls of the technical schools crowded with engineering students.

Once again, let us look over the picture. The fertile central west, with its intelligent, active and homogeneous people and the great engineering enterprises and Chicago strategically located in the eye of this great system so that it can and does direct the industries which radiate from this center. The increasing throngs of engineers equipped with the best technical educations which can be obtained, and the Western Society of Engineers the predominating engineering society of Chicago and of this Western empire.

Will this great West continue to develop?

Its growth will be greater than in the past.

Will Chicago continue to be the metropolis from which the industries of the West will be directed?

It is inevitable.

Will western engineers continue to associate together for companionship and the exchange of ideas?

As long as engineers are engineers.

Will they look to the halls of the Western Society of Engineers as the natural place for such meetings?

Not if our officers accept office merely for the honor of the election, and do not repay the Society in time, effort and zeal in the fulfillment of their duties. Not if the Board of Direction is content to drift along with matters of routine, and committees leave their work for the secretary to look after.

The Western Society cannot be the dominating Engineering Society of the west if the members expect that the officers alone can maintain its vigor. The responsibility placed upon the officers presumes an equal or greater responsibility upon the members. *They* are the ones who must furnish such good papers and good discussions that our meetings will be enthusiastic and profitable and will induce a stream of new recruits to swell our roster and our income, and so crowd our present rooms to the point of discomfort that we shall be able and will be compelled to seek larger and better quarters than those we now have.

We cannot hope always to have a Thirty Thousand Dollar beauty for president, or we would all want to be presidents. We can, however, always have reasonably good officers if we have active, critical and appreciative members. With such members and such officers we need not fear that the Western Society of Engineers will fail to take and maintain the foremost position among the engineering societies of this great and growing inland empire.

We would then be strong enough and wealthy enough to maintain Society rooms in keeping with the importance of the profession which we represent, and those of us who gave of our time and energy to its upbuilding, will have the satisfaction of knowing that we have assisted in a great, good and successful work.

Gentlemen, I thank you for the honor which you have done me in selecting me for your president for the coming year, and I accept the office in the hope that I may assist the Society a little to come into its own. I also accept with the mental reservation that the retiring president in donating a Thousand Dollars to our treasury has established a worthy precedent, to be observed on alternate years only.

ANNUAL REPORTS.

REPORT OF THE JUDGES OF ELECTION.

January 8, 1907.

To the Western Society of Engineers, Chicago.

GENTLEMEN: The undersigned Judges of Election, having canvassed the ballots cast for the officers of this Society for 1907, have the honor to report as follows:

Total number of ballots cast	323
Total number of ballots rejected as irregular	8
Total number of ballots counted	315
Number of votes cast for President, W. L. Abbott	308
Number of votes cast for First Vice President, Andrews Allen	306
Number of votes cast for Second Vice President, E. N. Layfield	302
Number of votes cast for Third Vice President, A. N. Talbot	310
Number of votes cast for Treasurer, Albert Reichmann	307
Number of votes cast for Trustee for three years:	
W. C. Armstrong	97
A. Bement	66
C. B. Burdick	28
L. E. Ritter	88

Respectfully submitted,

(Signed) GEO. N. LINDAY.
CHARLES B. GILLSON.
H. M. MORSE.

TREASURER'S REPORT FOR THE YEAR ENDING DECEMBER 31ST, 1906.

January 2nd, 1907.

To the Board of Direction, Western Society of Engineers, Chicago, Ill.

GENTLEMEN: I respectfully submit herewith a statement of the Treasurer's account for the year ending December 31st, 1906, as follows:

CASH STATEMENT.

January 1, 1906, cash in bank subject to check		$1,874.35
RECEIPTS.		
Dues	$7,349.00	
Entrance Fees	966.00	
Subscription to Journal	408.18	
Advertising	2,658.64	
Sales Journal	172.35	
Interest	310.40	
Journal Account	51.85	
Library Account	26.15	
House Expense	186.68	
Sta., Postage and Exchange	20.98	
Chanute Medal Fund Account	50.00	
General Printing	159.00	
		12,359.23
		$14,233.58

EXPENDITURES.

Journal Account	$3,982.71	
Library Account	819.63	
House Expense	2,588.67	
Sta., Postage and Exchange	697.01	
General Printing	767.98	
Services	1,500.00	
Furniture and Fixture Acct	37.80	
Investment Account	2,763.28	
Interest Account	23.40	
J. H. Warder (Spec. Acct.)	35.00	
		$13,215.48
Balance in Bank Dec. 31, 1906		1,018.10
		$14,233.58

SUMMARY.

Statement January 1st, 1906:

To credit Western Society of Engineers	$5,275.35
Chanute Medal Fund	1,099.00
	$6,374.35
Investments	4,500.00
Cash	1,874.35
	$6,374.35

Statement of January 1st, 1907:

To credit Western Society of Engineers	$7,079.10
Chanute Medal Fund	1,149.00
	$8,228.10
Investments	7,210.00
Cash	1,018.10
	$8,228.10

Respectfully submitted,

January 2nd, 1907. (Signed) ALBERT REICHMANN,
Treasurer.

SECRETARY'S REPORT.

Chicago, January 8, 1907.

To the Board of Direction, Western Society of Engineers, Chicago.

GENTLEMEN: Of the affairs of the Western Society of Engineers for the year 1906, I have the honor to report as follows:

The membership in the Society December 31, 1906, was 925, classified as follows:

Honorary members		1
Active members, resident	405	
Active members, non-resident	320	
		725
Associate members, resident	61	
Associate members, non-resident	12	
		73
Juniors, resident	87	
Juniors, non-resident	39	
		126
Total membership		925

From this number there will be some losses, such as resignations to be acted on, and members to be dropped, after January 1, 1907. But there were nineteen new applications for membership, endorsed by the Membership Committee, and duly elected at the meeting of the Board of Direction January 5, 1907, but who have not yet qualified.

The number of new members elected during 1906 was 105, but

Death has claimed	6
Resignations were accepted from	14
Dropped from membership	16
Total losses	36

which leaves a net gain to the Society during 1906 of 69.

There have been 15 transfers in grade in the Society as follows:

From Junior to Active	13
From Junior to Associate	1
From Associate to Active	1
	15

The death list in 1906 is as follows:
H. W. Parkhurst, Chicago, died April 7, 1906.
John Saltar, Jr., Philadelphia, died July 11, 1906.
A. W. Fiero, Chicago, died July 28, 1906.
F. P. Dobson, El Paso, Texas, died Aug. 25, 1906.
A. V. Abbott, New York, died Dec. 1, 1906.
O. B. Green, Chicago, died Dec. 30, 1906.

During the year 1906 there have been 29 called meetings, as follows:
1 Annual Meetings.
9 Regular Meetings, held the first Wednesdays in February, March, April, May, June, September, October, November, and December.
12 Extra Meetings of the Society.
7 Extra Meetings held by the Electrical Section.

A list of these meetings follows, which shows 31 separate papers or addresses, of which 15 were printed and sent out in advance of the meeting. Of these 31 papers and addresses, 11 papers were not published in the Journal for the year 1906, but most of them will be available for the Journal in 1907.

LIST OF MEETINGS IN 1906.

Tuesday, January 2:

The 36th Annual Meeting (No. 564) was held at the Sherman House and followed by a Dinner.

Wednesday, January 17:

Extra Meeting (No. 565). Mr. M. O. Leighton, of the United States Reclamation Service, presented a paper on "High Pressure Sluicing Gates."

Friday, January 26:

Extra Meeting (No. 566). 14th and annual meeting of the Electrical Section. Mr. Mason B. Starring, General Manager of the Chicago City Railway Co., presented a paper on "The Best Type of Electric Car for City Service."

Wednesday, February 7:

Regular Meeting (No. 567). A paper on the subject of "Areas of Waterways for Railroad Culverts," by Messrs. G. H. Bremner, James Dun, John W. Alvord, Louis Kingman, and others, was presented. (Paper printed and sent out in advance.)

Wednesday, February 21:

Extra Meeting (No. 568). Mr. S. F. Joor, M.W.S.E., read his paper on "Elevating and Conveying Machinery." (Paper printed and sent out in advance.)

Wednesday, March 7:
Extra Meeting (No. 569). Prof. E. G. Smith, M.W.S.E., presented his paper on "Urban Tendencies of Population as Affecting the Problems of the Engineer."

Friday, March 16:
Extra Meeting (No. 570). 15th meeting of the Electrical Section. Prof. P. B. Woodworth, M.W.S.E., read his paper on "Schools, Engineers and Employers."

Friday, March 23:
Extra Meeting (No. 571). A paper by Messrs. W. T. Curtis, M. W. S. E., and Josiah Gibson, M.W.S.E., on "A New Method of Calculating Bridge Stresses by Means of End Shears" was presented. (Paper printed and sent out in advance.) Prof. W. K. Hatt, of Purdue University, also addressed the meeting on "Physical and Mechanical Characteristics of Structural Timber."

Wednesday, April 4:
Regular Meeting (572). Mr. A. W. Merrick, M.W.S.E., presented his paper on "The Clay Slide at the Boone Viaduct, Boone, Iowa." (Paper printed and sent out in advance.)

Wednesday, April 18:
Extra Meeting (No. 573). Mr. C. H. Cartlidge, M.W.S.E., presented his paper on "Notes on the Design of Swing Bridges, etc." (Paper printed and sent out in advance.)

Friday, April 20:
Extra Meeting (No. 574). 16th meeting of Electrical Section. Mr. Albert Scheible, M.W.S.E., presented his paper on "What Degree of Accuracy is Feasible and Necessary in Wiring Calculations?"

Wednesday, May 2:
Regular Meeting (No. 575). A paper on the subject of "Development of Mechanical Filtration," prepared by Mr. R. E. Milligan, M.W.S.E., was read by Mr. J. W. Alvord, M.W.S.E.

Wednesday, May 16:
Extra Meeting (No. 576). A paper on "Fireproofing of Steel Buildings," by Gen. Wm. Sooy Smith, M.W.S.E., was read by the Secretary. Mr. W. H. Finley, M.W.S.E., also gave a talk on "The Design and Maintenance of Machinery for Swing Bridges," in further discussion of Mr. Cartlidge's paper on Swing Bridges.

Friday, May 18:
Extra Meeting (No. 577). 17th meeting of Electrical Section. Mr. H. R. King, M.W.S.E., presented his paper on "The Hawthorne Shops of the Western Electric Co."

Wednesday, June 6.
Regular Meeting (No. 578). A paper prepared by Prof. L. E. Ashbaugh, M.W.S.E., on the subject of "The Assessment of Drainage Districts," was read by the Secretary. (Paper printed and sent out in advance.)

Wednesday, June 13:
Extra Meeting (No. 579). Mr. A. J. Hammond, City Engineer of South Bend, Ind., read his paper on "The Jefferson Street Reinforced Concrete Arch Bridge," which was followed by a paper from Mr. O. E. Strehlow on the construction of this same bridge. (Paper printed and sent out in advance.)

Wednesday, September 5:
Regular Meeting (No. 580). Mr. W. L. Abbott, M.W.S.E., presented his paper on "Some Characteristics of Coal as Affecting Performance with Steam Boilers." (Paper printed and sent out in advance.)

Wednesday, September 19:
Extra Meeting (No. 581). Mr. A. S. Robinson, M.W.S.E., presented his paper on "The Proposed 'Inner Circle' System of Chicago Subway Terminals." (Paper printed and sent out in advance.)

Wednesday, October 3:
Regular Meeting (No. 582). Mr. A. Bement, M.W.S.E., presented his paper on "The Testing of Coal." (Paper printed and sent out in advance.)

Friday, October 12:
Special Extra Meeting (No. 583). Topical discussion, "Public Policy Demands a Waterway System," by Mr. L. E. Cooley, the Hon. Joseph E. Ransdell, Messrs. John A. Fox, Charles T. Harvey, Isham Randolph, and others.

Wednesday, October 17:
Extra Meeting (No. 584). Mr. A. Bement, M.W.S.E., presented his paper on "The Suppression of Industrial Smoke, with particular reference to Steam Boilers." (Paper printed and sent out in advance.)

Friday, October 19:
Extra Meeting (No. 585). 18th meeting of Electrical Section. Mr. P. Junkersfeld, M.W.S.E., presented his paper on "Electric Power Systems in Some European Cities."

Wednesday, November 7:
Regular Meeting (No. 586). A paper prepared by Mr. Charles H. Hudson, M.W.S.E., was read by his son, Mr. Charles Hudson, the subject being "Road Resistance." (Paper printed and sent out in advance.)

Friday, November 16:
Extra Meeting (No. 587). 19th meeting of Electrical Section. Mr. Geo. A. Damon, M.W.S.E., presented a paper on "What is an Engineer-Constructor?"

Wednesday, November 21:
Extra Meeting (No. 588). Mr. Edward DeKnight, of New York, read his paper on "Water-proofing, particularly as applicable to Masonry and Concrete Structures."

Monday, November 26:
Special-Extra Meeting (No. 589). Mr. R. S. Whipple, of Cambridge, England, read his paper on "Practical Pyrometry."

Wednesday, December 5:
Regular Meeting (No. 590). Mr. O. P. Chamberlain, M.W.S.E., presented his paper on "Concrete Pipe Culverts," which was followed by a paper from Mr. T. L. Condron, M.W.S.E., on "Tests of Bond Between Concrete and Steel." (Both papers printed and sent out in advance.)

Wednesday, December 19:
Extra Meeting (No. 591). Mr. F. W. Huels, of Madison, Wis., presented his paper on "Vibrations of passenger trains from electric lighting engines." (Paper printed and sent out in advance.)

Friday, December 21:
Extra Meeting (No. 592). 20th meeting of the Electrical Section. Mr. R. F. Schuchardt, M.W.S.E., presented his paper on "The Rotary Converter Sub-Station."

The matter of increasing the revenue of the Society has been under consideration by the Board of Direction during the past year, and in accordance with instructions, the Secretary has sent out to the members sundry circulars presenting the question of increasing the fees and dues, with the object in view of increasing the income of the Society. An amendment to the By-Laws was proposed by a Resolution presented at the regular meeting of the Society November 7th, and then sent out to the active membership for their approval by letter ballot. The result of this ballot was favorable to the proposed amendment to the By-Laws, fixing the fees and dues at a greater amount than heretofore, and as follows:

Entrance Fees for Active and Associate members	$12.50
Entrance Fees for Juniors	5.00
Annual Dues of Resident Active and Associate members	12.50
Annual Dues of Non-resident Active and Associate members	8.50
Annual Dues of Juniors to remain as heretofore, at	5.00

This increase of fees and dues to be effective after January 1st, 1907.

Very respectfully submitted,

(Signed) J. H. Warder,
Secretary.

LIBRARIAN'S REPORT.

Chicago, January 8, 1907.

To the Board of Direction, Western Society of Engineers, Chicago.

Gentlemen: The Librarian begs to submit the following report on the Library of the Society:

Number of books accessioned up to December 31, 1906	6,103
Number of books accessioned up to December 31, 1905	5,597
Additions to the library during 1906	506

These may be classified as follows:

Number of volumes of serials bound at the expense of the Society	153
Number of bound books—gifts to the Society and exchanges	305
Number of books purchased	21
Number of pamphlets accessioned	27
	506

The total net charge against the library for 1906 is $793.48, divided as follows:

Money expended on binding books	$169.95
Money expended on purchase of books	16.75
Money expended on services for library	554.50
Money expended on furniture & fixtures	37.80
Money expended on sundries	14.48
	$793.48

The number of books accessioned—506—is greater than for previous years, though only 21 books were cash purchases. But the number of books given to the Society by publishers and others is notable.

The largest item of expense of the library is that of services, amounting to $554.50. Of this the sum of $300.00 was expended in preparing a list of books in the library, with the object in view of having the same printed in pamphlet form for the use of the members and others. The printing of this list has not yet been done, but it is expected that the matter will be taken up this coming year.

The value of the Library and Reading Room is more and more appreciated, and is resorted to constantly by our members and the public also. But the need of additional space for the growing library is more and more urgent, and it is hoped that more room may be secured in the near future. It is the sincere hope and earnest desire of the Library Committee, the Board of Direction, and the Librarian, that before long means may be available to enlarge the quarters of the Society, including the Library and Reading Room, for the greater benefit to our members and the community.

Very Respectfully submitted,

(Signed) J. H. Warder,
Librarian.

BOOK REVIEWS.

Rock Minerals: Their Chemical and Physical Characters and their Determination in Thin Sections. By Joseph P. Iddings. Octavo, 548 pages, numerous figures through the text, 2 folded plates (1 in colors). John Wiley and Sons, New York. 1906. $5.00.

It is told of a certain professor, much given to writing text books, that he required each succeeding edition to be bound in a new color so as to easily assure himself that the students had purchased the latest. If there was as much difference as between Professor Iddings' new book and his well known translation from Rosenbusch, so long the standard, the device was well justified. As those who, a dozen years or more ago, studied the old Iddings-Rosenbusch text turn through the new volume they will be struck by the vast strides made by petrographers in that time. This is reflected in two characteristics of the new book; its inclusiveness and its precision. There are on the one hand, a large number of minerals described, which because of their rarity were formerly omitted from the text books, and on the other, new determinations and new methods permit of a precision which was formerly impossible. This is particularly exemplified in the treatment of the feldspars. Even a brief comparison of the methods now available with those taught to students, will reveal a wonderful progress in devices and determinations.

Professor Iddings has wisely expanded very greatly the general treatment of the subject which precedes the special description of the minerals. As he points out, students of petrography are supposed to come to it with a general knowledge of physical chemistry and co-ordinate subjects, but nevertheless need a review designed to point out the particular application of the science to the immediate problem. This attitude and treatment make the book rather one for beginners and general students of petrography, such as engineers, than for petrographers. The latter need the fuller references which would be useless to general students because of poor library facilities and defective command of foreign languages.

Among interesting developments recorded in this book are the disappearance of the familiar Nauman symbols; the definition of crystal habit in precise terms; the substitution of X. Y. Z. for $\mathfrak{A}$, $\mathfrak{B}$, $\mathfrak{C}$, the axes of fastest, medium and slowest vibration; and the large infusion of chemistry. The introduction of numerous figures in the text at the expense of the elaborate plates in the older book is a distinct improvement. The inclusion of the magnificent colored plate of birefrigences first used in "Les Mineraux des Roches" of Michael Levy will prove of daily service in every laboratory. It is to be hoped that the publishers have made arrangements for extra copies of this plate to be supplied separately.

The book is complete and up-to-date, including even such recent work as the studies of artificial feldspar and calcium silicates by Day and his associates of the Carnegie Institution. It is a text book of the highest class, not quite elementary enough perhaps for beginners who have any but the best of teachers, and yet a book of wide usefulness. If we might only hope that some one would treat the vein minerals with equal fullness, engineers interested in such subjects could well rest satisfied. H. F. B.

Boiler Waters: By William Wallace Christie, M. Am. Soc. M. E. D. Van Nostrand Co., New York. 235 p., 6 by 9 in., 71 illustrations, and many tables. Cloth. Price, $3.50.

This work, as the title implies, deals almost entirely with the subject of waters for use as steam boiler feed supplies. It is largely a compilation and resume of literature and writings on the subject covering a period of several years past, including many of the most recent publications relating to same.

The first chapter deals very largely with the scientific side of the subject, giving the chemistry and physical properties of many of the substances with which we have to contend, with slight allusions to different substances used in the treatment of water, both previous to entering the boiler and directly therein. This chapter also contains reports of analyses of many different waters, which no doubt will prove of considerable value to any person interested in the subject. In some cases, however, the reviewer does not believe that the results shown are sufficiently complete, as it is necessary many times, in order to judge the quality of a water for use as a boiler feed supply, to not only know the total amount of carbonates of lime and magnesia and the total amount of sulphates of lime and magnesia, but also to know the proportionate amount of each of the different salts mentioned, together with a quantitative statement of the amount of alkali salts, as well as other salts contained in the water itself,—for instance, nitrates. It is also the reviewer's opinion that the matter of deleterious effects such as are common in practice where waters contain proportionately large amounts of alkali salts is not given the consideration which it should have received, as ill effects from waters of this type in practice at the present time are almost as common as the troubles arising from waters which cause incrustation only. The methods and simple apparatus described for preliminary testing of water are deserving of compliment, as they will enable the engineer who is not a chemist, or anyone interested in the subject, to obtain much information previous to having a more complete analysis made, the latter, however, being always advisable.

The chapter on corrosion, as well as that on foaming, are also very good, but the more modern theories are in some cases absent.

The balance of the work treats very largely of heaters, mechanical devices for purifying, water softeners, etc., which are up to date and described very much in detail. The book as a whole is a very desirable one for the engineering chemist, and would, no doubt, prove of much value to the engineer himself, or other men in charge of a steam plant. The paper is high-class, the print is good, and the illustrations, which are numerous, are excellent. W. A. C.

RAILROAD LOCATION, SURVEYS AND ESTIMATES: By F. Lavis, Assoc. M. Am. Soc. C. E. New York: The Myron C. Clark Publishing Company. 6 by 9¼ ins.; pp. 270, with plates, illustrations, appendices, tables and index. Cloth. Price, $3.00.

The name of this work is not written alike on the title page and on the first page of the introduction. In the latter place there is a comma after the second word which would better be omitted. The heading "Railroad Location" which is placed on the top of the even numbered pages throughout the work is misleading. The book does not, and does not pretend to, discuss either the deepest principles or the broader problems of railroad location. The book comprises a very valuable discussion of the surveys and estimates to be made in railroad location in countries more or less undeveloped. The author discusses the subject as if topography alone determined the location of the line. Right of way values and business to be secured are outside of the scope of the work.

The work has been carefully compiled, but discusses *methods* rather than *principles*. The reader is supposed to understand the geometrical work of laying out curves, but he is not supposed to know how to mark stakes or pitch a tent. Thus the problems discussed are very practical; such as every engineer experienced in field railway surveying on new lines, remembers to have heard discussed a thousand times around his camp fires.

The work contains a great deal of the same matter as a paper published by the author in June, 1904, in TRANSACTIONS OF THE AMERICAN SOCIETY OF

Civil Engineers. As that paper was quite generally discussed by a number of prominent engineers and quite generally approved, and as the author has had broad experience in the field he covers, the work should become an authority in the limited field of engineering, of which it treats.

A quarter of a century ago there were no works in print discussing methods of conducting railway surveys. A young engineer came from college with his calculus, his "Henck," and his "Trautwine" under his arm, but he had to learn how to use his book knowledge after he had come into the field, by serving a sort of apprenticeship, oftentimes under quite illiterate men. He might be able to calculate his notes for laying out a curve, but he did not know how to set up his transit; he might know the theory of compound curves, but he couldn't lay out a spiral on the ground.

Not only is the student of today much better and more practically trained in school but the literature available is so complete that he can gain in a few weeks' reading as much general information in regard to special fields of engineering, as it formerly required years of experience to acquire.

Witness what has been done in this special field of railway construction. Both *Beahan* and *Lavis* have told how surveys should be conducted; *Waite* and *Johnson* tell the young railway engineer how to prepare his contracts and to write his specifications and *Gillette* tells him how to handle his material.

But the reviewer takes issue squarely with the author in his idea that the students in college will be materially benefited "by going through the book under the guidance of their instructor," or in other words, by using the work as a text book.

The reviewer has had some experience both in the school room and in the special field covered by this work, and he is convinced that neither this work, nor any work that deals for the most part with methods, is suitable for a text book. Students in college need intellectual drill and they tire quickly of a study of methods. The time when men become interested in methods is when they try to execute and fail. Only then does "method" appeal to them.

The reviewer has learned with surprise that Beahan's "Field Practice of Railway Location" is being used as a text in railway engineering in some of the leading engineering schools. It is certain that Mr. Beahan did not write his work for a text book. Such works as it and the one under discussion will serve nicely to supply material for a short course of lectures by the teacher or to cover the field of readings assigned to the student. But even the average engineering student is better employed in college in reading choice English Literature or in studying Political Economy or the fundamentals of some Science than in learning descriptive matter as to how anything is done, even if it is as interesting a subject as how to project a paper railway location.

The best use the work will serve, and here it is indispensable, is in informing the young railway engineer how to proceed after he has finished his college course and begun his professional work in the particular field of railway location, in countries more or less undeveloped. W. D. T.

Alternating Current Motors. By A. S. McAllister, Ph. D., New York, N. Y. McGraw Publishing Co., 272 pages, 6 by 9 in.; numerous illustrations. Cloth. Price $3.00

A close reading of this book will convince the reader that the author is familiar not only with the theoretical foundation of the design of alternating current motors but with the experimental results which may be observed by test. In the preface the author refers to the fact that many writers use terms without proper discrimination in such a manner as to confuse even a well posted reader. Apparently this source of trouble is entirely absent and the book is greatly enhanced thereby. Mathematics including integral calcular is used. Numerous vector diagrams are also used to show the relation of the various quantities. An excellent feature of the work is that whenever mathematics or diagrams are used the conclusions to be arrived at are clearly and concisely summed up in the reading matter. This is a great advantage to the reader who is not able to make proper deductions from formulas or diagrams.

The first pages are devoted to a review of methods of measuring power on alternating current circuits, and of the economical use of conducting material. The phenomena of the induction motor dealing with the production of the revolving field is next taken up. After the better known principles are considered, the Heyland induction motor is discussed. In chapter VI single phase induction motors are considered. Various methods of obtaining rotary fields on single phase circuits, both with and without a commutator, are considered. Next the graphical treatment of induction motors and numerous data giving the performance which may be expected from machines are included. The chapter on induction motors used as generators is at present of little commercial interest; however, the insight into the use of commutators with them, aids in forming a foundation for the treatise on single phase commutator motors which is considered later.

Approximately the last half of the book is devoted to single phase commutator motors, including the repulsion, the straight series, the compensated series and numerous modifications of these fundamental types which have only recently become of commercial importance. The treatment of this subject is probably the most complete and concise in print at the present time. Previous to the publication of this work the only articles pertaining to the subject were to be found in various periodicals and proceedings of technical societies. It is a great pleasure to find this scattered information combined in a complete and logical manner. W. J. W.

PRACTICAL METAL TURNING: A handbook for machinists, technical students and amateurs. By Joseph G. Horner, 404 pages, including index; 488 illustrations. New York. Norman W. Henley Publishing Co. Cloth, 8x5½ in. Price $3.50.

This is an excellent work, though the style and some of the illlustrations betray its English origin. Certain terms employed do not sound natural to a Yankee, yet one acquainted with the subject would not be confused. He would find the book full of valuable information if at all conversant with the subject. To a technical student or a "prentice" eager to learn all he can of his craft, the book will be found "pleasant reading." After the introduction, which explains the relation between the lathe shop, and the other parts of a machine works, the subject matter is classed under Section I, The Lathe, its work and the tools. Section II, Turning between centres. Section III, Work supported at one end. Section IV, Internal work. Section V, Screw cutting and turret (lathe) work; and finally Section VI, Miscellaneous matters, which includes special work—Measurement, Grinding, Tool Holders, Tool Steels (special) with speeds and feeds, for rapid work.

The advent of these "High Speed Steel" cutting tools has introduced great changes in the output of the lathe shop, over that of an earlier generation of workmen, and the instructions for the working of the steel for these cutting tools is very properly introduced at the end of the book. The appliances for holding the work as chucks of various forms and designs, are interesting to one who recalls some of the difficulties experienced in his "prentice days," and he thinks with regret how he would have revelled in such a work as this in those early eager and enthusiastic days, when to be put at lathe work was counted as quite an advance, and almost as a "reward of merit" for previous good behavior in the shop. W.

THE DESIGN OF STEEL MILL BUILDINGS, AND THE CALCULATION OF STRESSES IN FRAMED STRUCTURES. By Milo S. Ketchum, C. E., Professor of Civil Engineering, University of Colorado. Second Edition, *Engineering News,* New York, 1906. Cloth, 6 by 9 in., pp. 480. $4.00.

The well deserved favor with which the first edition of this work was received has inspired the author, in bringing out the second edition, to add many valuable pages, making it still more of a standard, not only for the student, but also for the practicing engineer.

The evident and justifiable fondness of the author for the graphic method of solving the various problems presented to the designer of steel mill buildings and other structures has led him to develop this method in various directions, the most notable, perhaps, being a very full discussion of influence diagrams and methods of calculating the deflection of beams. The graphic method is also applied to the calculations of reactions and wind stresses in transverse bents.

Tables of "Concentrated Live Loads" and "Allowable Pressures," as proposed by Mr. C. C. Schneider, are inserted for the use of the working designer whose further needs are also provided for, by the addition of fifteen pages of standard dimensions of structural shapes and details taken from the American Bridge Company Standards.

The subject of "Stresses in Pins" is carefully treated, but there is room for much to be said regarding the calculation of stresses in columns under eccentric loading, especially columns carrying crane runways on brackets.

The principles governing the calculation of the reactions of continuous beams, and their application to the design of draw bridges, form the subject of an additional section.

The Modified Saw Tooth Roof proposed by the author in the first edition is elaborated in the present volume, and the advantages of this form of construction are emphasized. The report of a committee on Skylight Construction for Railway Train Sheds is also inserted.

Additional examples are given of notable building construction, including a standard reinforced concrete roundhouse—which one would hardly expect to find in a volume devoted to Steel Mill Building.

The book closes with a large number of problems covering a variety of principles and special designs, solved by the graphic method and serving to make clear to the student the manner of applying to practical ends the principles enunciated in the preceding pages.

The new matter in the second edition greatly increases its value and will add much to its usefulness, both as a text book and a working tool.

W. L. C.

ELECTRICAL WIRING AND CONSTRUCTION TABLES. By Henry C. Horstmann and Victor H. Tousley. 119 pages with index. 6 by 4¼ in.; flexible leather. Price $1.50.

This pocket hand-book, brought out by two electrical inspectors of the city of Chicago, has decided points of originality, and from cover to cover seems to be an earnest attempt to compile the tables most needed by practical men who are not familiar with higher mathematics.

One of its novel features consists in a clever arrangement of "Efficiency Numbers" to allow for the varying efficiency of motors, without obliging the user to figure percentages. Another is a table for quickly estimating the total lengths of wire needed for distributing from a single point to a number of outlets spaced evenly. This table, together with the clear diagrams showing the sizes of wires which can be drawn through conduits of various sizes, ought to save a good deal of time for those figuring work under Chicago or similar conditions. The dimensions of wires and conduits are also given quite fully, as are the sizes of wires taken by different dimensions of mouldings and cleats, but curiously enough there is no table showing the sizes of porcelain tubes required for the different wire sizes.

The tables for both alternating and direct current wire are largely graphical, and unfortunately are drawn with such fine lines that they will require very sharp eyes as soon as the pages become slightly soiled. Those for the alternating wiring certainly should have been on a considerably larger scale to insure their being usable for any length of time.

One whole chapter is devoted to the "Economy of Conductors," with a view to utilizing the old rule that the most economical loss in distribution is that at which the annual waste of energy equals the interest charged on the cost of line construction necessary to save it. Unfortunately, the authors have nullified the benefit of this chapter by not distinguishing between the *average* and the *maximum* energy loss. The rule certainly would seem to apply only to the average loss, and the average current very rarely equals the maximum for which the safe capacity of the line has been planned. No distinction has been made between the two in this chapter, and the example given is worked out on the assumption that the line will always carry the maximum current, which means a result considerably different to that implied by the average current, and hence the average energy loss.

The miscellaneous tables have unfortunately been limited to the lamps controlled by the Westinghouse Company, but the series of Standard Symbols for wiring plans, as recently adopted by the National Electrical Contractors Association, have wisely been added. In a number of cases some of the blank space on the pages could have been used to advantage for a clearer explanation of the adjoining tables, which may otherwise puzzle some of the practical men whom this volume should reach. On page 70, the formulae for Ohm's Law are the old ones limited to direct current calculations, which ought to be stated; or better still, the expanded forms should also be given for alternating current calculations.

Excepting for these shortcomings, the volume is unusually practical and deserves a wide distribution. A. S.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for December, 1906, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

University of Illinois, Urbana, Ill., 4 pamphlets—
  "Tests of Concrete," by A. N. Talbot. I, Shear; II, Bond.
  "Fuel Tests with Illinois Coals," by Breckenridge, Parr and Dircks. Bulletins No. 6 and 7.
  Bulletin, Water Survey Series No. 3.

Engineering News Publishing Co., New York, "Universal Dictionary of Mechanical Drawing," by Follows. 1906. Cloth.

Norman W. Henley Publishing Co., New York, four cloth bound volumes—
  "Punches, Dies and Tools for Manufacturing in Presses." 1907. Woodworth.
  "Modern Milling Machines," by Joseph Horner. 1906.
  "Practical Metal Turning," by Joseph Horner. 1906.
  "Tools for Machinists and Woodworkers," by Horner. 1906.

D. Van Nostrand Company, New York, "Boiler-waters; scale, corrosion, foaming." By W. W. Christie. 1906. Cloth.

Frederick J. Drake & Co., Chicago, "Electrical Wiring and Construction Tables," by Horstmann and Tousley. 1907.

Mines Branch, Department of Interior, Ottawa, Canada, "Report of Commission appointed to investigate the zinc resources of British Columbia and its conditions affecting their exploitation." Pamphlet. 1906.

Otis F. Clapp, City Engineer of Providence, R. I., Annual Report of City Engineer for 1905. Pamphlet.

J. A. Jamieson, Montreal, Can. "Grain Pressures in Deep Bins." 1903.

Purdue University, Lafayette, Ind. Bulletin No. 2, Nov., 1906. Annual Reports President and other Officers, 1905-6. Pam.

Wm. O. Seymour, Railroad Commissioner of Connecticut, 54th annual report, 1906. Cloth.

Robert R. McCormick, Sanitary District of Chicago, "Report by Rudolph Hering and Geo. W. Fuller, made to International Waterways Commission on the disposal of the sewage of Chicago and the Calumet region." 1906. Pam.

Armour Institute of Technology, Chicago, Fourteenth annual Year-Book, 1906-7. Pam.

Dr. W. Michaelis, M. W. S. E., Chicago, "The Constitution of Hydraulic Cements." 1906. Pam.

Carnegie Institution of Washington, Year Book No. 5, 1906. Pam.

Ohio State Board of Health, Twentieth annual report, 1905. Cloth.

American Society of Civil Engineers, Blue List of Jan. 15, 1907. Pam.

Col. W. H. Bixby, M. W. S. E., Chicago, "Report upon the Chicago Drainage Canal, by the International Waterways Commission. Jan. 4, 1907." Pam.

Maine State Railroad Commissioners, 48th annual report, 1906. Cloth.

Massachusetts Institute of Technology, two pamphlets—
  Bulletin No. 2; annual reports President and other Officers, 1905-6.
  President's report, 1907.

Mining and Scientific Press, of San Francisco; Chicago Office; "After Earthquake and Fire." Cloth.

Prof. L. P. Breckenridge, M. W. S. E., University of Illinois, Urbana, Ill., Bulletins of Engineering Experiment Station, Nos. 1-8, 1904-6 Half leather.

BOOKS PURCHASED.

Busquet, R., A Manual of Hydraulics. 1906.
Chamberlain, T. C., and R. D. Salisbury, Geology; vols. 2 and 3. 1906.
Day, John V., The Prehistoric Use of Iron and Steel. 1877.
Dowson, J. E., and A. T. Larter, Producer Gas. 1906.
Fowler, Chas. E., Ordinary Foundations. 1906.
Gentsch, W., Steam Turbines. 1906.
Haines, Henry S., Restrictive Railway Legislation. 1905.
Hall, Joseph, The Iron Question. 1857.
Mathot, R. E., Gas Engines and Producer-Gas Plants. 1905.
Merriman, Mansfield, Mechanics of Materials. 1906.
New York. Report and Testimony of the Special Committee of the Assembly to Investigate the Desirability of Municipal Ownership of Street and Elevated Railroads of the various cities of the state. Vols. 1 and 2. 1896.
Parsons, H. de B., The Disposal of Municipal Refuse.
Poor's Railroad Manual for 1906.
Ries, Heinrich, Clays. 1906.
Thomas, Carl C., Steam Turbines. 1906.
Venable, William M., Garbage Crematories in America. 1906.
Wehrenfennig, Edmund, Analysis and Softening of Boiler Feed-water. 1906.
Williams, Ralph D., The Honorable Peter White. A biographical sketch of the Lake Superior Iron Country. 1905.
Wyer, Samuel S., A Treatise on Gas-Producers and Producer-Gas. 1906.
Engineering Index, Vol. IV, 1901-1905.

GOVERNMENT PUBLICATIONS.

U. S. Dept. of Commerce and Labor, Report of Supt. of Coast and Geodetic Survey. 1906. Cloth.

U. S. Dept. of Commerce and Labor, Bureau of the Census, Bulletins Nos. 58, 59, 61, 62, 63, 65, 68, and 69. Pamphlets.

U. S. Dept. of Agriculture, Forest Service, Circulars Nos. 45, 46, 48, 49 and 53. Pamphlets.
Report of The Forester for 1906, by Pinchot. Pamphlet.
U. S. Dept. of Agriculture, Forest Service, Bulletin 72. Pamphlet.
U. S. Dept. of Agriculture, Weather Bureau, Weather Bulletin No. 361.
"Climatology of the United States, by Henry. 1906. Cloth.
U. S. Geological Survey, Department of Interior, Reclamation Service, Specifications Nos. 125, 126, 127, 128, 129, 130.
U. S. Geological Survey, Department of Interior—
Bulletins Nos. 283, 284, 285, 289, 290, 292, 293, 295, 298, 299, 301, 302. Pams.
Water Supply and Irrigation Papers, Nos. 159, 160, 161, 162, 164, 172, 174, 175, 177, 179, 180, 181, 184, 185, 186.
Professional Papers Nos. 46, 51, 52, 54 and 55. Pams.
Summary of Mineral Production of the United States in 1905. Pam.

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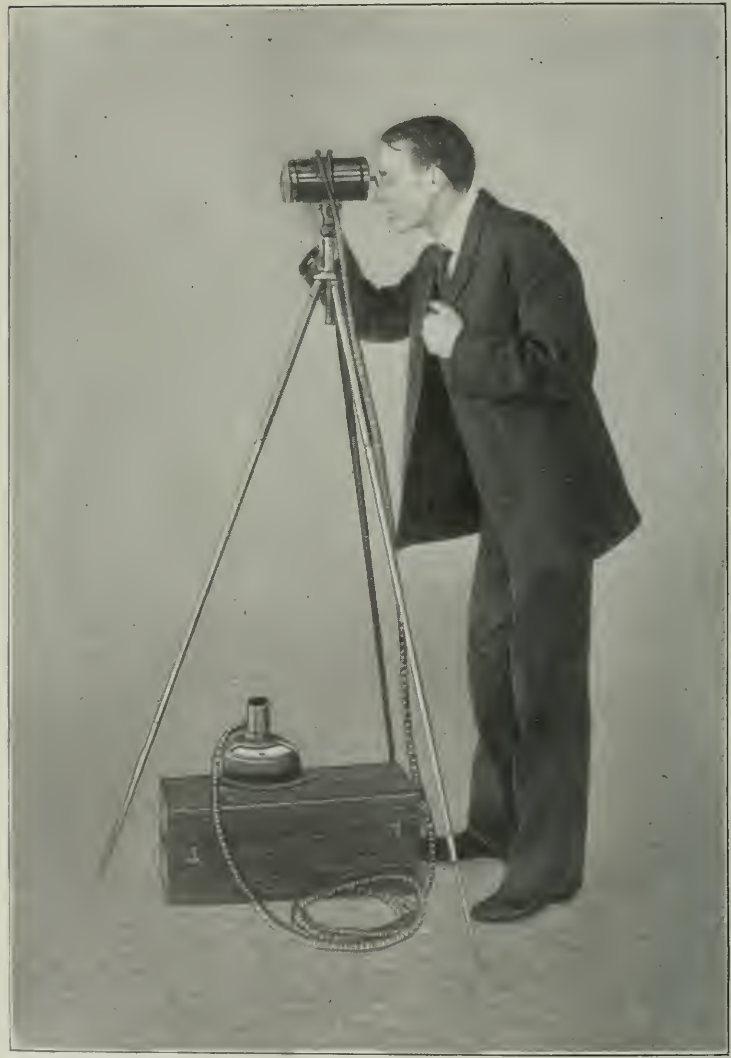

Fig. 25.

A Féry Pyrometer in use.

Journal of the
Western Society of Engineers.

VOL. XII. APRIL, 1907. NO. 2.

PRACTICAL PYROMETRY.

By Robert S. Whipple,

Vice-president Cambridge Scientific Instrument Co., Ltd., Cambridge, England.

Presented November 26, 1906.

Although we are, perhaps, apt to laugh at the very rough methods adopted by our predecessors for the measurement of temperature, it cannot be denied that the accurate measurement of temperature is still a problem of considerable difficulty. Temperature is not a measurable quantity in the strict sense of the term. To measure a length or a mass is to count how many times it is necessary to take a given body chosen as a unit (metre or gramme, as the case may be) in order to obtain a system equivalent, either as to length or mass, of the body in question. The possibility of such a measurement assumes the existence of two laws—that of equality, and that of addition. Temperature obeys the first of these laws. Two bodies in temperature equilibrium with a third will also be in equilibirium with each other. The other law is entirely lacking. You cannot by placing together several bodies at one temperature, realize a system equivalent, from the point of view of exchange of heat, to a body at a different temperature.

Many scales of temperature have been proposed, but the gas scale is the one now universally adopted, and readings obtained by any type of thermometer—electrical, expansion, or optical—are reduced to temperatures on the gas scale. The gas scale has been adopted as the standard scale of temperature—firstly, because gas of the same purity can be reproduced at any time; secondly, the dilatation of the gas, which defines the scale of temperature, is sufficient for accurate measurement; and, thirdly, the scale is practically identical with the thermodynamic scale.

Although the scale of the gas thermometer has become the standard of reference, yet, fortunately, we are not compelled to use the gas thermometer in every-day life. We do not employ an elaborate gas thermometer, with its adjuncts of telescopes, microscopes, and standard barometer, every time we wish to measure a

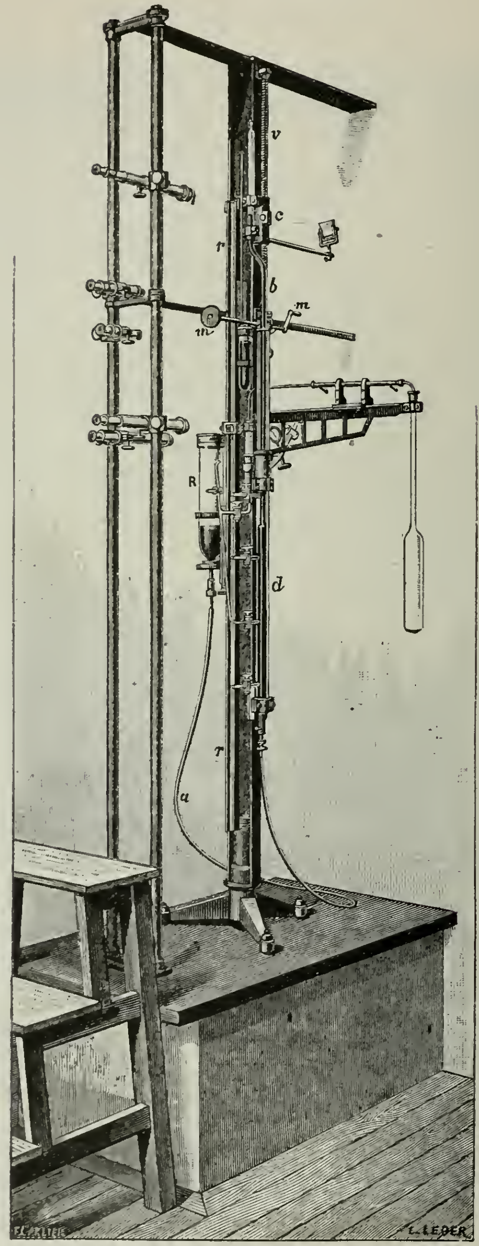

Fig. 1.

temperature; but we use a thermometer which has been carefully standardised at certain known temperatures. Fig. 1 illustrates one of the gas thermometers in use at the Bureau des Arts et Métiers, Paris, and shows clearly that the instrument is rather a complicated piece of apparatus. Dr. Arthur L. Day has succeeded in eliminating various sources of error which have previously been present in these thermometers, and I think that perhaps the Carnegie Institute at Washington now possesses the most accurate gas thermometer in the world.

Thermometers, and under this name I include pyrometers, are generally standardised by means of fixed points of fusion and ebullition determined by the gas thermometer.

It is, perhaps, for this very reason that many of the discrepancies in high temperature thermometry have arisen. The actual precision of the high temperature measurements depends on the degree of accuracy to which these fixed points are known. It has at present been found impossible to determine many of these directly on the gas thermometer, as even the platinum-iridium bulb of the gas thermometer becomes porous at extremely high temperatures. High temperature thermometry is badly handicapped through the scarcity of materials capable of being made into a thermometer bulb and of standing high temperatures. Platinum—the great stand-by—has been shown by Sainte-Claire-Deville and others, to be very permeable to hydrogen—a gas which is generally present where combustion is incomplete. Fortunately, platinum, even when red-hot, is practically impervious to all other gases; so that if nitrogen is employed as the gas whose volume we are measuring, and the platinum is suitably protected from hydrogen, accurate observations may be made. Porcelain must be glazed to ensure non-permeability, and the glaze cannot be considered impermeable above 1100 deg. Cent. Water vapour passes comparatively rapidly through unglazed porcelain.

In passing, one cannot help being struck with the inter-dependence of all branches of scientific work. At the first thought it would not occur to one that the accurate determination of the value of the metre would be the means of producing the most accurate thermometry the world has seen; yet so it has been. To determine the length of a standard bar it is essential that its temperature should be known accurately; to measure the temperature accurately, the constants of the thermometer employed must be known to a high degree of precision, and these can only be obtained from an elaborate system of comparators, gas thermometers, etc. Thus the preliminary work on the measurement of the metre produced the masterly work of Dr. Ch. Guillaume on the mercury thermometer and his valuable treatise "Thermométrie de Précision."

I cannot here enter into the details of the construction and working of a gas-thermometer, and would refer those who are especially interested to Dr. Guillaume's book previously mentioned, or to Dr. Burgess' translation of M. Le Chatelier's book "High Temperature Measurements."* I must acknowledge my indebtedness to the latter book for some of the facts mentioned in this paper.

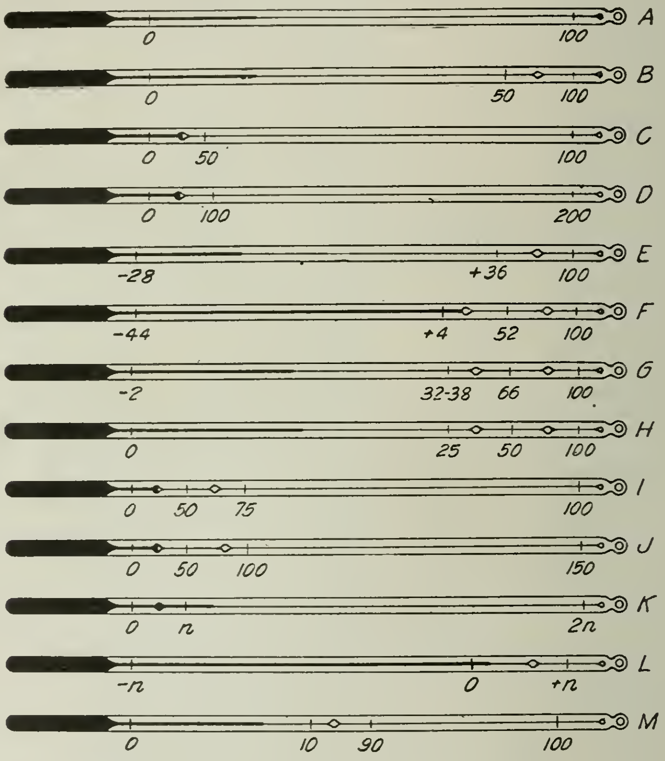

FIG. 2.

GROUP OF STANDARD MERCURY THERMOMETERS.

As previously stated, the gas-thermometer, although invaluable from the strictly scientific point of view, is practically useless as a tool in every-day life. It will be well, therefore, to summarize roughly the various means of measuring temperature in general use, and then to treat these methods more fully in detail with their particular applications:

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* Wiley and Sons, New York.

TYPES OF THERMOMETERS IN GENERAL USE

		Type	Range in Degrees Centigrade over which they can be used
Expansion	Those depending on the change in volume or length of a body with temperature.	Gas	0° to 1000°
		Mercury, Jena glass and nitrogen	—40° to 500°
		Glass and spirit or petrol	—200° to +40°
		Unequal expansion of metal rods	0° to 500°
		Contraction of porcelain	0° to 1800°
Transpiration and Viscosity	Those depending on the flow of gases through capillary tubes or small apertures.	The Uehling	0° to 1600°
Thermo-electric	Those depending on the electromotive force developed by the difference in temperature of two similar thermo-electric junctions opposed to one another.	Galvanometric	0° to 1600°
		Potentiometric	0° to 1600°
Electric Resistance	Those utilizing the increase in electric resistance of a wire with temperature.	Direct reading on Indicator or Bridge and Galvanometer	0° to 1200° 0° to 1200°
Radiation	Those depending on the heat radiated by hot bodies.	Thermo-couple in focus of mirror	0° to 10,000°
		Bolometer	0° to 10,000°
Optical	Those utilizing the change in the brightness or in the wave-length of the light emitted by an incandescent body.	Photometric Comparison	0° to 2000°
		Incandescent filament in telescope	0° to 2000°
		Nicol with quartz plate and analyzer	0° to 2000°
Calorimetric	Those depending on the specific heat of a body raised to a high temperature.	Copper or platinum ball with water vessel	0° to 1500°
Fusion	Those depending on the unequal fusibility of various metals or earthenware blocks of varied composition	Alloys of various fusibilities	0° to 1980°

Dr. Charles Chree, F. R. S., in some valuable "Notes on Thermometry," published in the Philosophical Magazine for March, 1898, makes the statement that "the ideal mercury thermometer is one which accommodates itself at once and completely to the temperature it is for the time being exposed to, and which when exposed to a given temperature, supplies an invariable reading."

I think there could not be a better definition of what is required from any form of thermometer.

EXPANSION THERMOMETERS.—Although the gas thermometer is essentially an expansion instrument, yet the mercury in glass thermometer must be considered as the expansion instrument *par excellence*. Many of us know how far the mercury thermometer, as generally used, falls short of Dr. Chree's ideal, but I think few of us realise how near Dr. Guillaume has brought us to that ideal. It is now possbile, thanks to his work, to measure temperature with a mercury thermometer, to an accuracy of 0.001 deg. Cent.

It is sad to think how far we in America and Great Britain have been behind French and German practice in the construction of accurate mercury thermometers; more especially when it is borne in mind that Kew standards, as made under the direction of Balfour Stewart and Welsh, were for many years the standards of the world. I can only account for it by the fact that we were standing still whilst the National Physical Laboratories of France and Germany were developing the construction and materials of their thermometers. This reproach has now been removed, and you, with your Bureau of Standards under the far-seeing direction of Prof. Stratton, and we, with our National Physical Laboratory under Dr. Glazebrook, are doing work which will take rank with that of the Continental National Laboratories.

There is no necessity for me to explain the details of construction of a mercury thermometer to you. Fig. 2 illustrates a group of Standard thermometers capable of the highest precision work. It will be noticed that all the thermometers have the two fundamental points of zero and 100 deg. cent. engraved upon their stems for purposes of standardization. The enlargements in the capillary bore are made in order that a much more open scale of degrees may be used than would be otherwise possible; it necessitates, however, the employment of several thermometers to obtain the complete scale.

Now that nitrogen is being introduced into the stem of the thermometers above the mercury they may be used up to temperatures as high as 500 Deg. C. Glass thermometers filled with petrol may be used to measure temperatures as low as —200 Deg. C. Fig. 3 is the reproduction of a record of air temperature obtained with a mercury thermometer and recorded automatically on a sheet of paper mounted on a clock-driven drum. The thermometer is so mounted that with a change of temperature the position of a style relatively to the paper is altered, these alterations being automat-

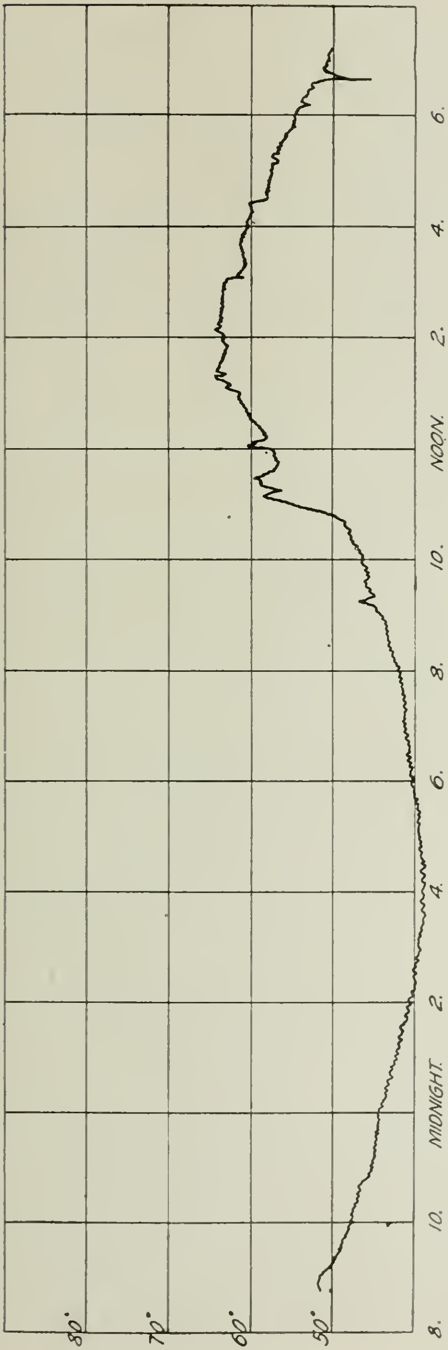

FIG. 3.

REPRODUCTION OF RECORD ATTAINED WITH A RECORDING MERCURY THERMOMETER.

ically recorded. The details of the recording mechanism will be explained when describing the thread-recorder further on in this paper.

An expansion thermometer of general interest is the one in which temperature is measured by the unequal expansion of two materials, such as steel and porcelain or graphite.

A graphite rod is placed at the bottom of a closed steel tube, a small steel tube being connected to the upper end of the graphite rod. By means of various simple mechanical movements the differential expansion of the two rods is indicated on a dial. These thermometers are useful up to temperatures of about 500 deg. cent. but cannot be relied upon for measurements of an accuracy higher than 10 per cent.

TRANSPIRATION AND VISCOSITY.—The *Uehling* and *Steinhart* thermometer is based on the resistance to the flow of gases through two apertures. One of these apertures is exposed to the high temperature to be measured so that the gas after entering the aperture has obtained this temperature. The other aperture is maintained at a constant temperature, generally 100 Deg. C. Air under constant head is drawn through the two openings. Two manometer tubes are connected to the chambers into which the apertures open and an inverted bell jar floating in mercury records the differences in pressure between them. These differences in pressure can be readily converted into the difference in temperature between the gases entering the two apertures.

THERMO-ELECTRIC.—I now come to what I may call the third group, the thermo-electric thermometers, in which is measured the electromotive force developed by the difference in temperature of two similar thermo-electric junctions opposed to one another. Becquerel was, as far as is known, the first to use this method of measuring high temperatures (1830). He used a platinum-palladium couple. His son, Edmund Becquerel, was the first to realise the importance of using a high resistance galvanometer with a thermo-couple. The *electromotive force* is a function of the temperature, and as it is the current strength that is measured, it is important that the resistance of the whole circuit should be as nearly as possible constant; that is to say, the change in resistance of the couple itself should be small as compared with the change in the rest of the circuit. For some time the thermo-electric method was regarded with suspicion, Regnault having observed such irregularities in the couples in use that he condemned the method unreservedly.

Chatelier showed that very few combinations of wires make satisfactory couples. Iron, nickel, palladium, and their alloys are absolutely unsuited for the measurement of high temperatures, since when heated, these wires give rise to parasitical currents which may be relatively intense. He found that platinum and its alloys with iridium and rhodium are, fortunately, free from these faults. Of all the couples, those consisting of platinum and an alloy of platinum with ten per cent of rhodium are the most durable for use at extremely high temperatures. On the other hand, a platinum and platinum ten per cent iridium couple gives a larger electromotive force, and therefore a more open scale.

Some recent works by Holborn and others* have shown that the change (decrease) in the e. m. f. of two Pt. and Pt. Ir. (10% Ir.) thermo-couples due to glowing at 1100 deg. cent. for eight hours amounted to 6% and 14%, while the change (increase) in the e. m. f. of a Pt. and Pt. Rh. (10% Rh.) thermo-couple, exposed to similar conditions, was only 0.5%.

Some exceedingly interesting work by Dr. W. P. White† of the Carnegie Institute shows that the iridium sublimes slowly at temperatures above 1200 deg. cent. and enters and contaminates the platinum side of the thermo-element. The effect of this contamination is to make the element read too low. Iron vapour has also been shown to have the same effect. It has been known for a long while that unprotected platinum, when exposed to furnace gases deteriorated rapidly, but this deterioration has been put down to the action of the furnace gases rather than to the volatile metals. I feel there is still room for further research on the deterioration of thermo-couples, but all the results show the importance of protecting the couples with glazed porcelain tubes.

Two methods are generally employed to measure the electromotive force of a thermo-couple; the *potentiometric* or the method of compensation, and the *galvanometric*. The first method is rather cumbrous for general workshop use, but it is undoubtedly the more accurate. It consists in balancing the e. m. f. given by the unequally heated junctions against the drop of potential between two points in a circuit produced by an accumulator or other steady battery. A cadmium cell is arranged for reference as the standard of e. m. f. This method has the advantage of avoiding any error due to the resistance of the thermo-junction itself or the leads connecting it to the potentiometer. The arrangement of the apparatus is shown in Fig. 4. A slide wire of known resistance A. B. is connected in series with a suitable resistance R and rheostat K; an accumulator Ac being arranged to produce a steady current through the circuit. One terminal of the galvanometer, G, is connected to one end of the slide wire and the other G, to a two-way switch S, one contact of which is connected to the standard cell, C, the other to the thermo-couple, T.

The current in the circuit is adjusted by the rheostat until there is a fall of potential, say 30 millvolts, along the slide wire. The slide wire contact is then shifted until a balance is obtained, when the e. m. f. of the thermo-couple is read off on the scale. The scale is sometimes arranged to read directly in temperatures.

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* Holborn and Henning—Sitzung ber. der Konigl. Preuss. Akad. d. Wissensch. S. 936, 1992.

† Physical Review, December, 1906.

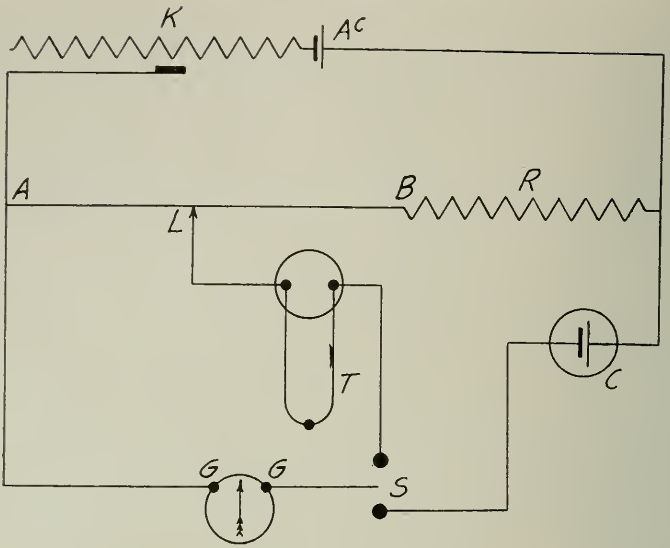

FIG. 4.

DIAGRAM SHOWING METHOD OF DETERMINING TEMPERATURES WITH A THERMO-COUPLE AND POTENTIOMETER.

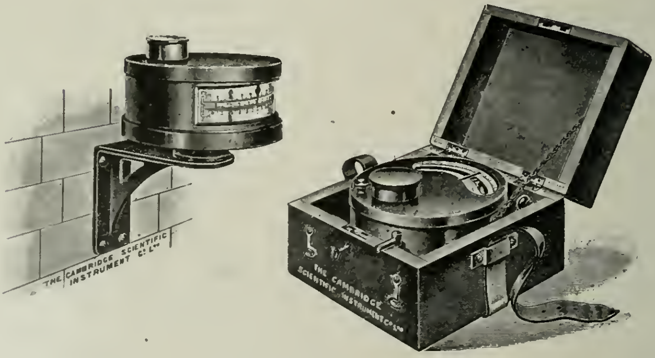
THE CAMBRIDGE SCIENTIFIC INSTRUMENT Co Ltd
THE CAMBRIDGE SCIENTIFIC INSTRUMENT Co Ltd

FIG. 5.

DIRECT READING GALVANOMETER FOR USE WITH THERMO-COUPLES.

The *galvanometric* method is simplicity itself, the cold ends of the thermo-couple wires being connected directly to the galvanometer terminals. If the resistance of the circuit is constant, the deflections will be proportional to the electro-motive force. The majority of direct reading instruments consist of a sensitive D'Arsonval galvanometer, the coil of which either carries a miror reflecting a spot of light on to a scale or a boom pointing to a scale. The galvanometer scale is divided in millivolts and degrees Centigrade; fig. 5 shows two types of galvanometers very frequently used for this purpose.

The advantages of the galvanometric method are portability and simplicity; the disadvantages, closeness of scale, and the fact that an error is introduced by the variation in resistance of the couple.

The potentiometric method has the advantages of an open scale, and that no error is introduced by the resistance of the couple. The only serious disadvantage is the fact that the apparatus must be worked in a laboratory, and requires a trained observer.

A simple form of recorder which may be used with thermo-electric couples is one to which the name "Thread Recorder" has been given. In it the galvanometer pointer A, Fig. 6, is depressed every minute by a guillotine D on to an inked thread G, which is forced against the paper wrapped round the drum C, leaving a small ink mark behind on the paper. The ink on the thread is renewed by means of a simple winding mechanism. This method of recording gives rectangular co-ordinates and entirely prevents the blotting or smudging of the record.

The clock-work mechanism can be made to depress two or more galvanometer booms simultaneously, the various galvanometers being connected to different thermometers. Fig. 7 illustrates an instrument for taking four records, the records obtained are entirely independent of each other and the thermometers may be working over widely different ranges. Fig. 8 is a reproduction of a record obtained with a platinum and platinum-rhodium couple used in conjunction with a thread recorder; Fig. 9 is interesting as a record of the temperature of the flue of a small furnace obtained with an inexpensive thermo-couple, copper-constantin.

ELECTRIC-RESISTANCE THERMOMETERS.—The electric-resistance thermometer was first proposed by Sir William Siemens in the Bakerian Lecture of 1871, and it immediately came into general use in metallurgical work. Unfortunately, it was found that the pyrometer did not satisfy the fundamental criterion of always giving the same indication at the same temperature, and it was rather severely condemned by a committee of the British Association in 1874, who showed that these changes in resistance were due to chemical alteration in the platinum and defective contacts between the fine wire of the coil and the comparatively heavy conducting leads.

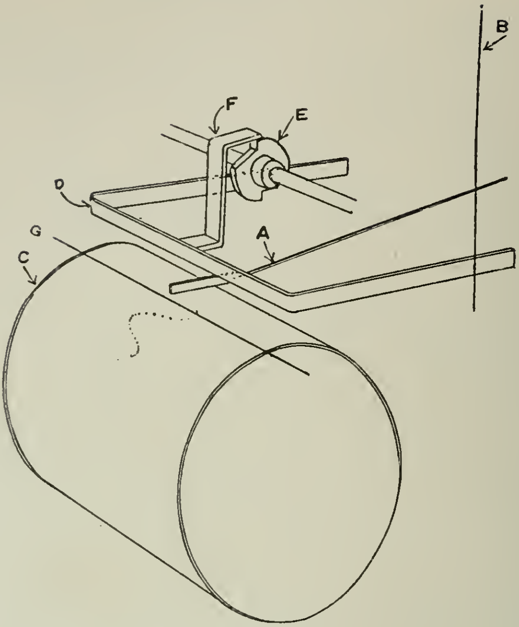

FIG. 6.

ESSENTIAL PARTS OF A THREAD RECORDER.

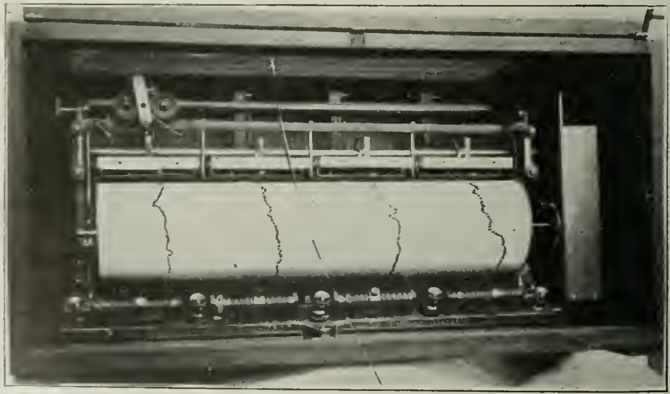

Fig. 7.

In 1886 Professor Callendar showed* that if the platinum is supported on a mica frame, in section that of a cross with equal arms, there is perfect insulation without any cause of alteration. He also showed that all joints in the wires should be made by fusion. Metallic solderings are volatile and attack platinum, and screw joints become loose. I cannot enter into a description of the classical work of Professor Callendar on this subject, but would refer anyone interested to a paper published by him in the Philosophical Magazine, February, 1899, entitled "Notes on Platinum Thermometry," which gives an excellent summary of his work. The results of his researches—and they have since been confirmed by many workers—show that the platinum-resistance thermometer, if protected from strain and contamination, is practically free from zero changes over a range of 0 to 1200 Deg. C., and that it always gives the same indication at the same temperature. He also showed that different platinum wires agreed very closely in giving the same value of any temperature on the platinum scale, although they differed considerаby in the values of their temperature coefficients.

Professor Callendar pointed out that if R_0 denote the resistance of the spiral of a particular platinum thermometer at 0 deg. and R_1 its resistance at 100 deg., we may establish for the particular wire a temperature scale, which we may call the scale of platinum temperatures, such that, if R be the resistance at any temperature on

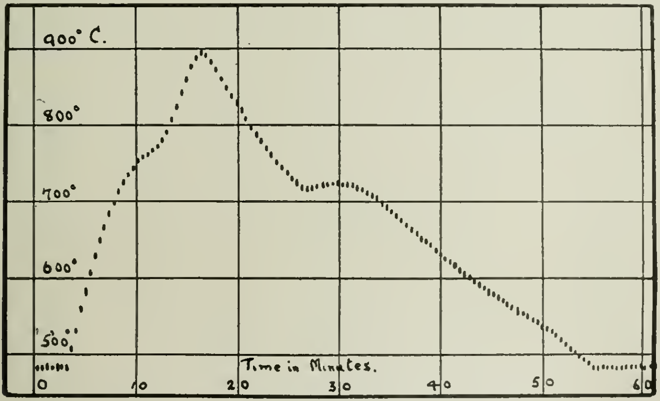

FIG. 8.

RECALESCENCE POINT ATTAINED WITH A PTATINUM—PLATINUM-RHODIUM COUPLE AND PATENT THREAD RECORDER.

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* Practical Measurement of Temperature, H. L. Callendar, Phil. Trans. Roy.Soc. A. 1887.

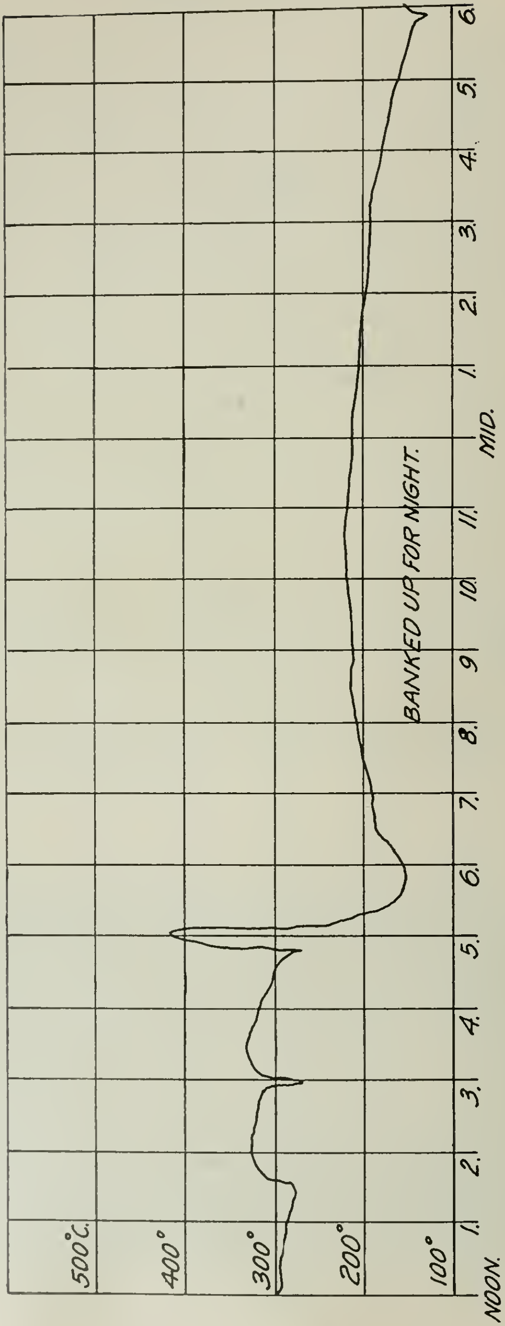

FIG. 9.

TEMPERATURE OF FLUE. RECORD ATTAINED WITH COPPER-CONSTANTIN COUPLE AND THREAD RECORDER.

the air scale, the temperature on the platinum scale will be $\frac{R - R_0}{R_1 - R_0} \times 100$. For this quantity he employs the symbol *pt*, its value depending on the sample of platinum chosen. In order to reduce temperatures on the platinum scale to the gas scale, it is necessary to know the law connecting T and *pt*. They are, of course, identical at 0 deg. and 100 Deg., and experiment has shown that the formula

$$T - pt = \Delta\left[\left(\frac{T}{100}\right)^2 - \frac{T}{100}\right]$$

expresses the curve of the relationship between them in other parts of the scale. The value of Δ depends on the purity of the platinum wire used; it can be obtained from observations at three known temperatures. A table of corrections is used to convert temperatures on the platinum scale to those on the gas scale, or the instruments used with the thermometers may be read directly on the gas scale.

As now constructed the *platinum resistance* thermometer consists of a fine platinum wire wound on a mica frame connected by means of stout copper or platinum leads to terminals in the head of the thermometer. Two similar leads, but unconnected to the coil, pass through the whole length of the thermometer, and act as compensating leads. By this means no error is introduced by the variation of the temperature of the wires connecting the thermometer with the indicator or recorder. The diagram, Fig. 10, explains the general arrangement for the use of Callendar and Griffiths' resistance thermometer. The thermometer coil forms one arm of

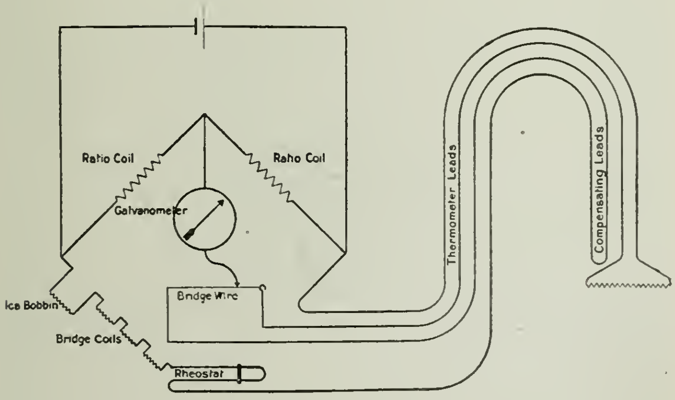

FIG. 10.

DIAGRAM SHOWING METHOD OF MEASURING TEMPERATURE WITH A COLLANDER & GRIFFITHS RESISTANCE THERMOMETER.

the bridge, whilst the compensating leads and the balancing coils form the opposite arm; a pair of equal ratio arms are generally used. The resistance of the thermometer varies with the temperature, the resistance of bridge-coils and bridge-wire being adjusted so that no current passes through the galvanometer at the moment of taking the temperature. The coils and bridge-wire have been calibrated in terms of temperature.

If temperature measurements are to be made with a resistance thermometer to a high degree of accuracy, a specially designed Wheatstone bridge and a sensitive galvanometer must be employed. This arrangement, however, is too cumbrous for general commercial use, and I have designed a bridge,* Fig. 11, which is a modification of one invented by Professor Callendar and Principal Griffiths, in which the temperature values are read directly in degrees Centigrade, and rapidly-varying temperatures may be followed. The instrument is especially useful for measuring the temperatures of boiler flues, general testing and annealing work, etc.

Dr. Edwin F. Northrup has designed an ingenious instrument which he calls a *ratiometer* in which the temperature measurements are made directly on a scale, no manipulative action being required on the part of the observer†

In Fig. 12 is shown the method of connecting an indicator in turn, by means of a switchboard, with a large number of thermometers distributed throughout a cold storage warehouse.

The construction of some typical resistance thermometers is shown in Fig. 13. The platinum resistance coil is seen at the bottom of the porcelain or steel tube, the coil being connected to the stouter platinum leads. In the annealing furnace type of thermometer (the

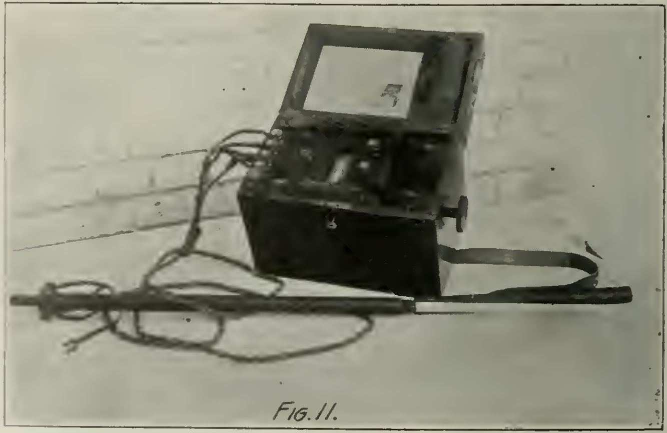

FIG. 11.

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* *Engineering*, May 16th, 1902. Vol. LXXIII., p. 645.

† Northrup, E. W., Proc. American Inst. Elect. Engineers, 1906, p. 241.

thermometer on the right, Fig. 13) the porcelain tube is protected by an easily renewable heavy steel sheath.

Professor H. L. Callendar has designed a recording instrument for use with resistance thermometers. It consists of a Wheatstone bridge in which the movement of the slider along the bridge-wire is automatically effected by delicate relays worked by the current passing through the galvanometer between the bridge arms. According as the moving coil of this galvanometer is deflected in one direction or the other, a relay circuit is connected through one or other of two electro-magnets. Each of these magnets is mounted on a clock, the movement of which is prevented by a brake. When the current energises a magnet, this brake is lifted, allowing the

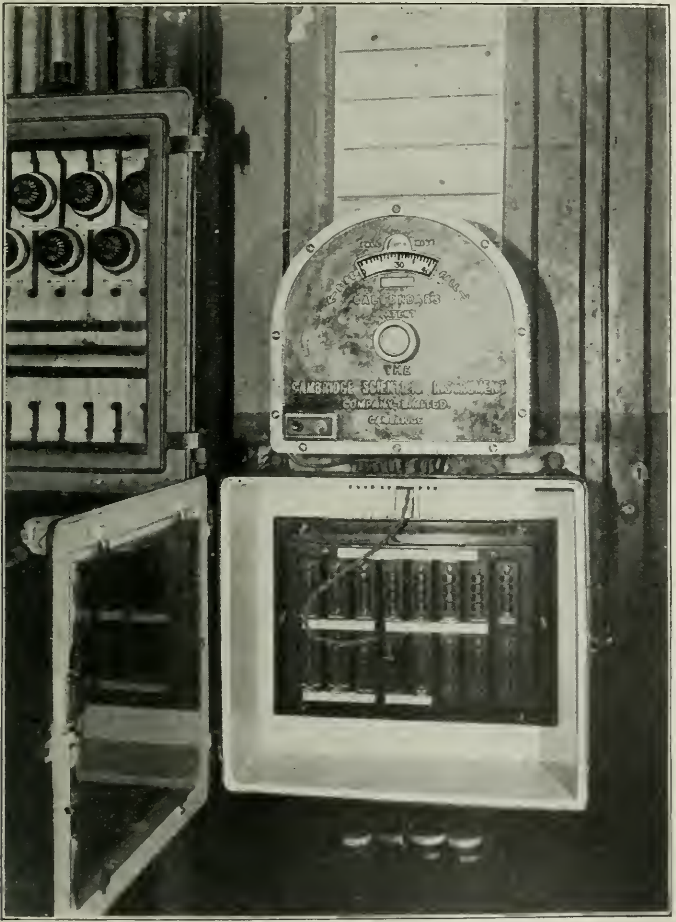

Fig. 12.

clockwork to revolve. The clocks are connected by differential gearing with a recording pen, which is pulled in one direction or the other, according as the brake is lifted from the corresponding clock. The bridge slider moves with the pen and tends to restore balance.

In Fig. 14 is illustrated the latest commercial form of the recorder; Fig. 15 showing the electrical connections.

The uses to which a satisfactory recorder can be put are almost innumerable. In Fig. 16 two recalescent curves are produced; one record (A) being characteristic of a mild grade of steel (0.35 per cent carbon), the other (B) of a finer steel. A comparison shows

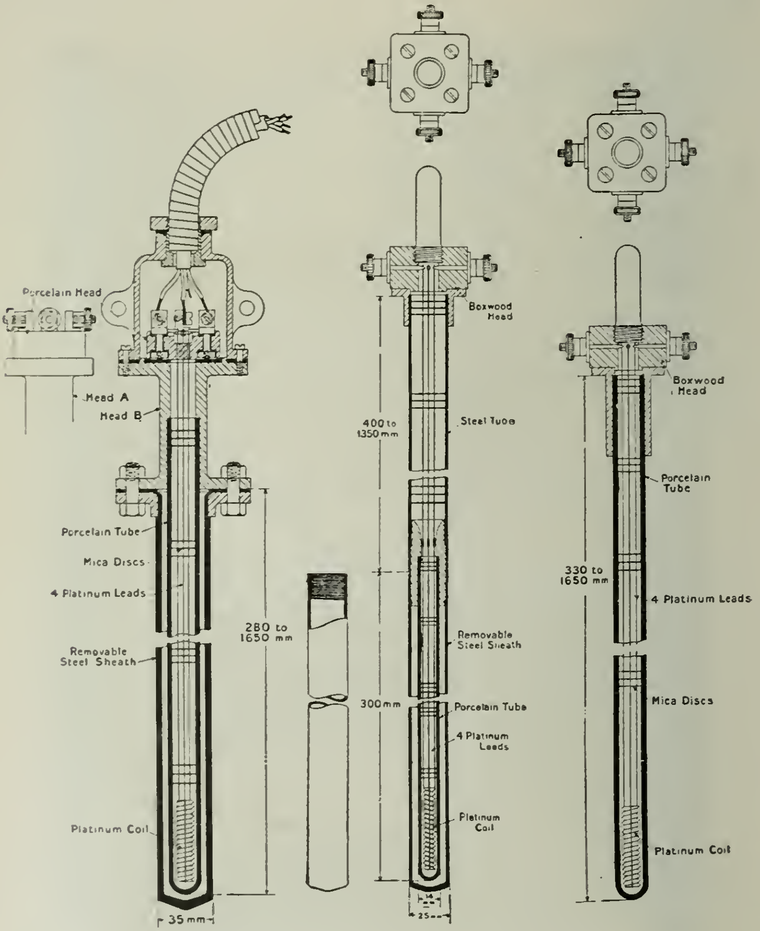

FIG. 13. TYPES OF CALLENDAR & GRIFFITHS RESISTANCE THERMOMETERS.

clearly the value of such records in discriminating between different qualities of steel.

On every hand we hear of the "heat treatment" of steel, and anyone who has had to do with annealing knows the difficulty of maintaining the ovens or furnaces at a constant temperature. The fireman will go to sleep, and will swear that he was awake the whole night through, and in many cases will aver still more strongly that the correct temperature was maintained all the time, the master only learning a few days later from the tests

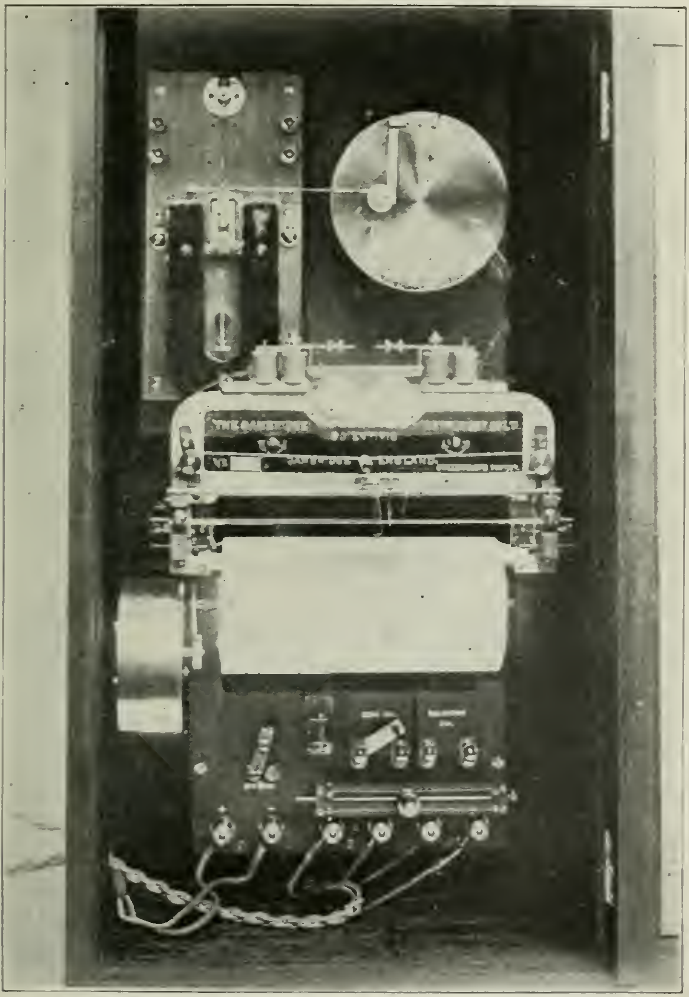

Fig. 14.

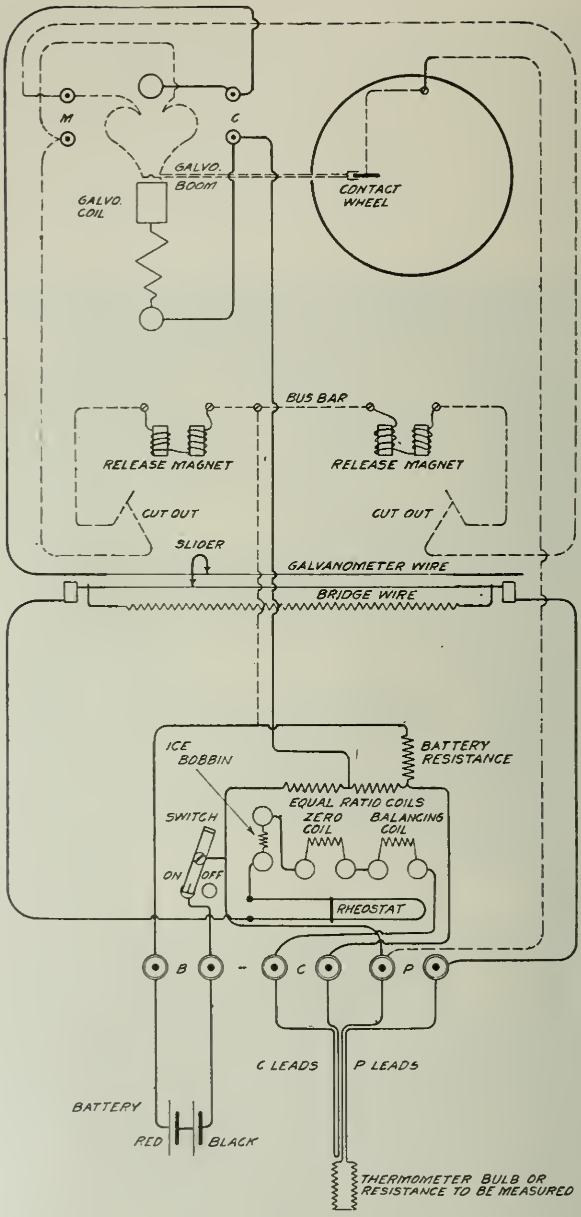

FIG. 15

ELECTRICAL CONNECTIONS OF CALLENDAR ELECTRIC RECORDER WITH PYROMETER.

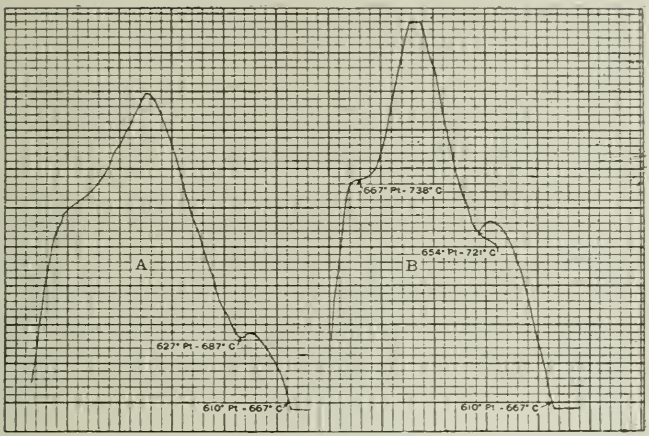

FIG. 16.

TWO RECORDS ATTAINED WITH A RESISTANCE THERMOMETER AND CALLENDAR RECORDER. THE RECALESCENT POINTS ARE WELL MARKED. ONE RECORD (A) BEING CHARACTERISTIC OF A MILD GRADE OF STEEL (0.35 PER CENT CARBON), THE OTHER (B) OF A FINER STEEL (0.9 PER CENT CARBON).

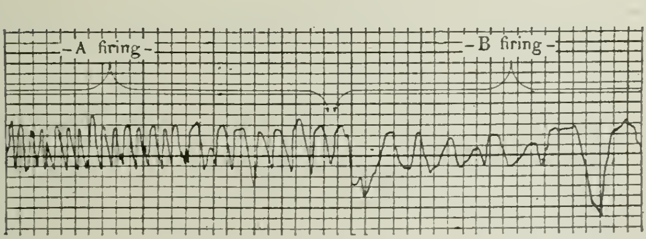

FIG. 17.

ANNEALING FURNACE RECORD. THE DIFFERENCE IN THE FIRING OF THE TWO MEN "A" & "B" IS INTERESTING. THE TEMPERATURE IS ABOV 700°C. EACH SPACE IN THE VERTICAL CORRESPONDS TO FOUR CENTIGRADE DEGREES.

on the material how badly the furnace had been fired. The record, Fig. 17, has been kindly given by a firm who employ several of these recorders, and it explains how they have overcome the difficulty. The difference in the firing between the two men—the old experienced hand and the new man, who fires more frequently—is very striking.

Resistance thermometers can be placed at a considerable distance from the reading instrument and for this reason they have been found useful for measuring temperatures of the soil and the temperature of cold stores.

I will now give some instances where resistance thermometers are being used for more strictly scientific work. The first case is, perhaps, one of the most important. Messrs. Heycock and Neville, whose work on the determination of the melting-points of metals is so well known, have recently been investigating the behaviour of the copper-tin alloys.* This important research in which many different alloys were included was carried out by means of these thermometers, and a Callendar electric recorder. Fig. 18 is reproduced from this paper and shows clearly the marked influence in the freezing point of the alloy made by slightly altering its composition.

The next example will show how extremely small a resistance thermometer may be made. The illustration, Fig. 19, is taken from Callendar and Nicholson's paper on the "Law of Condensation of Steam."† The thermometer was fixed in the piston-rod of a steam-engine, and its temperature read by means of a cycle contact-maker, bridge, and galvanometer. A record obtained with a similar thermometer inserted in the cylinder cover is reproduced in Fig. 20. The most striking feature of the curve is the great superheating shown at the end of the compression.

Professor Howard T. Barnes has published some exceedingly interesting results of temperature measurements made with resistance thermometers in the St. Lawrence River.‡ His measurements were made with a pair of differential thermometers and the values obtained could be relied upon to 0.0001 Deg. C.

The observations obtained were the means of satisfactorily explaining the formation of Anchor Ice. In the same paper Dr. Barnes mentions the fact that he is "successfully operating a thermometer placed nearly a mile away from the place of observation."

HEAT RADIATION AND OPTICAL THERMOMETERS.—Many workers have endeavoured to evolve a pyrometer that would measure the temperature of a source of heat without the necessity of inserting

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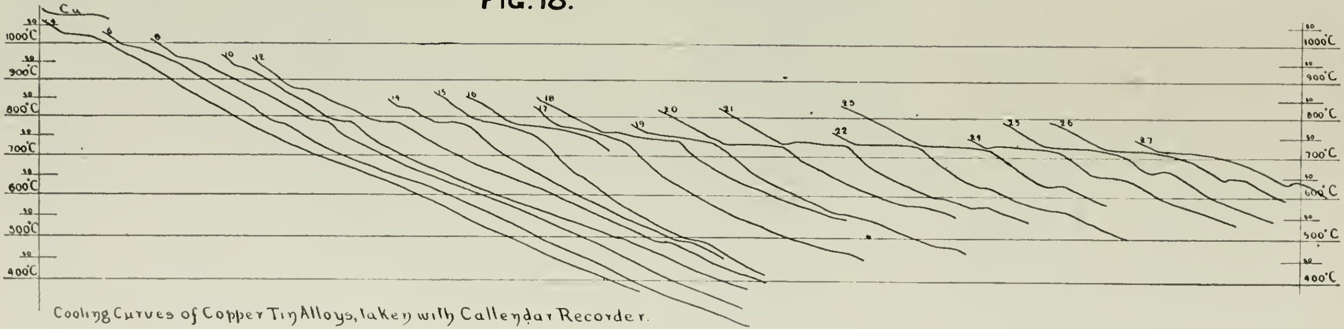
*Heycock & Neville. Bakerian Lecture "On the Constitution of the Copper-Tin Series of Alloys." *Phil. Trans.* Roy. Soc. Lond. A. Vol. 202, 1903.

† Proc. Civil Engineers, London. Vol. CXXXI., page 23.

‡ H. T. Barnes, "Formation of Anchor Ice and Precise Temperature Measurements." *Trans. American Soc. Mech. Eng.* XXVI. p. 558.

COOLING CURVES OF COPPER-TIN ALLOYS.

FIG. 18.



Cooling Curves of Copper Tin Alloys, taken with Callendar Recorder.

Time is measured horizontally, Centigrade Temperature vertically.

The numerals near beginning of each Cooling Curve give Atomic Percentage of Tin in the Alloy of the Curve.

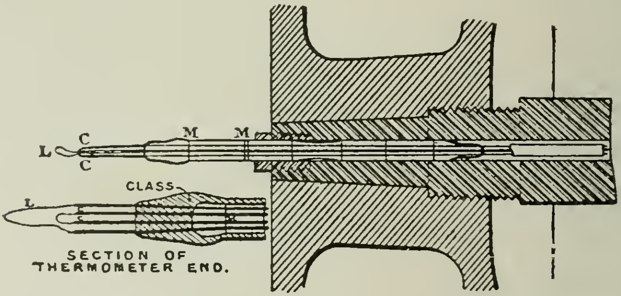
Curves are given for Alloys between Sn_4 and Sn_{27}.

Equal vertical distances correspond to equal differences of Temperature on the Platinum Scale.

a "poker," as I believe you, on this side of the water, call the ordinary pyrometer.

Taking optical pyrometers first, I think that on the whole the so-called absorption one invented by Professor C. Féry is the most successful. It is an improved form of the original optical Pyrometer of Le Chatelier and has been found useful for measuring the temperature of incandescent filaments and other extremely hot but small bodies.

It consists essentially of a telescope, D, B, Fig. 21, which carries a small comparison-lamp (E) attached laterally. The image of the flame of this lamp is projected on a miror (F) at 45 Deg. placed at the principal focus of the telescope, the mirror being silvered only over a narrow vertical strip (*a*, *b*, Fig. 21*a*). The telescope is



SECTION OF PISTON SHOWING PLATINUM THERMOMETER.

FIG. 19.

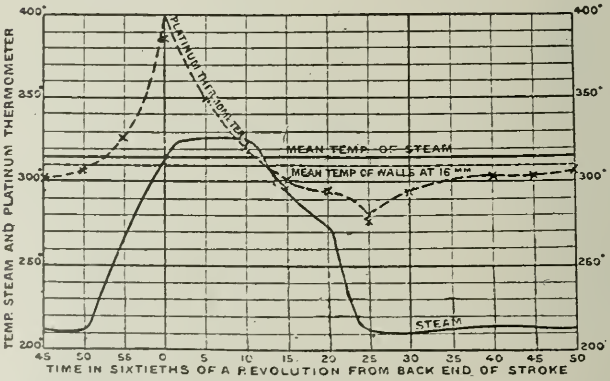


FIG. 20.

RECORD OF THE CHANGES IN TEMPERATURE OF AN ENGINE CYLINDER DURING A STROKE.

focussed on the object the temperature of which it is desired to measure, the object being viewed on either side of the silvered strip. A pair of absorbing-glass wedges (C and C_1) are placed in front of the objective of the telescope and these wedges are moved laterally by means of a micrometer screw until the light from the object under observation is made photometrically equal to that emitted by the standard lamp. An auxiliary dark glass (D) is also fitted to enable the instrument to work over a higher range of temperature. A table provided with the instrument converts the readings obtained by the scale and micrometer into degrees Centigrade. Fig. 21*a* shows the telescope focussed on a small crucible, the narrow silvered vertical strip being clearly shown. The instrument designed by Professor Wanner has also been successful. Instead of using monochromatic light as in the case of the Féry and Chatelier Optical Pyrometer, the light is spread out into a spectrum by a direct vision spectroscope, and a small region in the red is used, Fig. 22. The working standard source of light is a small incandescent lamp. The method of reducing the two fields of light from the hot body and the electric light respectively to the same intensity, is first to polarise them in planes at right angles to each other, and then the intensity of each can be varied by viewing them through a Nicol's prism, which can be rotated. This angular rotation of the Nicol is then a measure of the intensity of the light, and therefore of the temperature. The incandescent lamp can be standardised against an amyl-acetate flame. Owing to the loss of light in the optical system of the pyrometer, the lower limit of temperature measurement is about 900 deg. cent.

In Mesuré and Nouel's Pyrometer Telescope an attempt is made to control temperatures by taking advantage of the rotation of the plane of polarization of light passing through a quartz plate cut

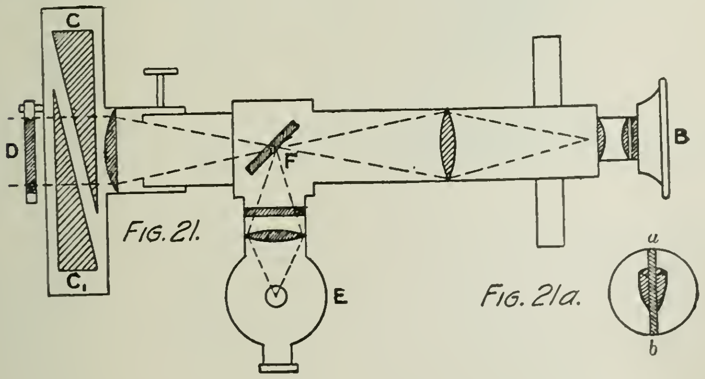


FIG. 21.

FIG. 21a.

DIAGRAMMATIC ARRANGEMENT OF A FERY ABSORPTION PYROMETER.

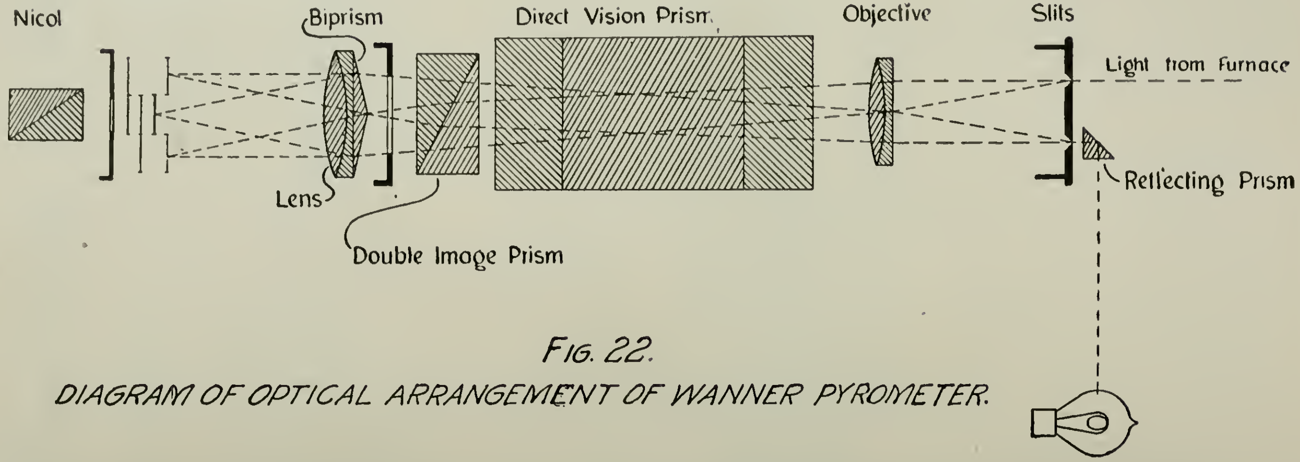


FIG. 22.
DIAGRAM OF OPTICAL ARRANGEMENT OF WANNER PYROMETER.

perpendicular to its axis. The angle of rotation is directly proportional to the thickness of the quartz, and approximately inversely proportional to the square of the wave length. In general the field of view will be coloured, and by turning the analyzer, the colour observed will change because the light, all polarized in the same plane, emerging from the first Nicol is polarized by the quartz in various planes depending on the wave length, so that the angle between the two "Nicols" determines the colour that will be seen. This instrument has the advantage over others that it has no auxiliary apparatus, but it lacks sensibility.

An ingenious optical pyrometer has been designed by Holborn and Kurlbaum, working at the Physikalische-Technische Reichsanstalt. An incandescent filament, L. Fig. 23, is placed in the focus of the eye-piece of a telescope, and by means of an object-glass an image of the source of heat is thrown into the same plane. The current passing through the filament is regulated by means of a rheostat until the filament is no longer visible on the image of the source of heat, when both sources of light will have the same intensity.

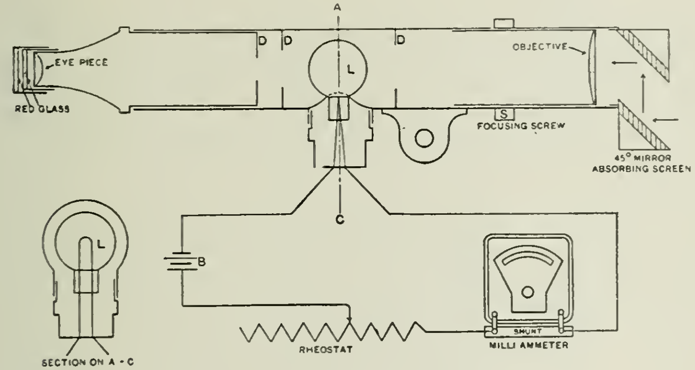


Fig. 23.

DIAGRAMMATIC ARRANGEMENT OF HOLBORN-KURLBAUM OPTICAL PYROMETER.

The Morse gauge is a simplified form of the same thermometer.

The most successful radiation pyrometer is that invented by Professor C. Féry of the "Ecole de Physique et de Chimie," Paris. The radiation which emanates from a hot body, or which passes out through an observation hole in the wall of a furnace, falls upon a concave mirror, M. Fig. 24, and is thus brought to a focus. In this focus is a thermo-electric couple, D, whose temperature is raised by the radiation falling upon it; the hotter the furnace, the greater the rise in the temperature of the couple.

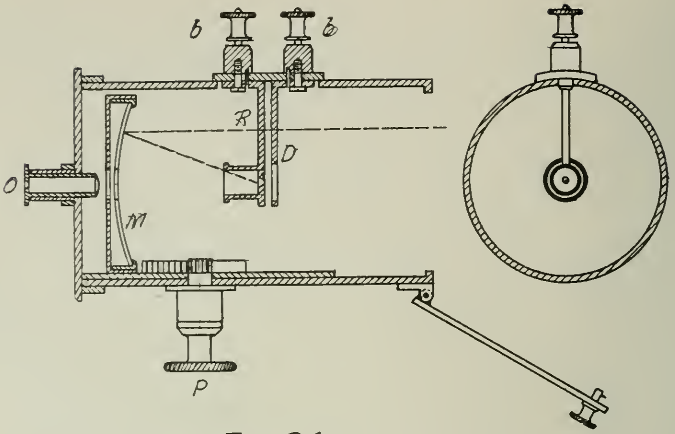


FIG. 24.

FERY RADIATION PYROMETER TELESCOPE.

The electro-motive force generated by the couple actuates a sensitive galvanometer, the scale of which is based upon the Stefan-Boltzman radiation law which expresses the relation between the temperature of a body and the amount of radiant energy which it emits, viz.: that "The radiant energy emitted by a black body is proportional to the fourth power of the absolute temperature of the body."

The arrangement of the instruments is such that they are uninfluenced, within wide limits, by the size of the hot body or observation hole on the one hand, or on the other by the distance which separates them from the hot body or furnace. Fig. 25 (frontispiece) illustrates the method of measuring a temperature by means of this pyrometer; the observer is shown focusing the pyrometer on a source of heat. The thread-recorder previously described may be used in conjunction with the pyrometer, some interesting records having been obtained in this way. Fig. 26 is a reproduction of a record of the temperature of a steel annealing furnace and Fig. 27 of the temperature of a Pottery "Biscuit" kiln. These records are especially interesting when it is considered that no part of the instrument was inserted into the source of heat.

Professor Langley designed a radiometric apparatus under the name of a *bolometer,* which has since been largely developed by Professor Callendar for measuring heat radiations, more particularly solar radiations. It consists of a differential pair of flat platinum thermometers, one blackened and the other bright, placed side by side in the same horizontal plane in a hermetically sealed glass vessel. The difference of temperature between the two, which is automatically recorded on a Callendar Electric Recorder,

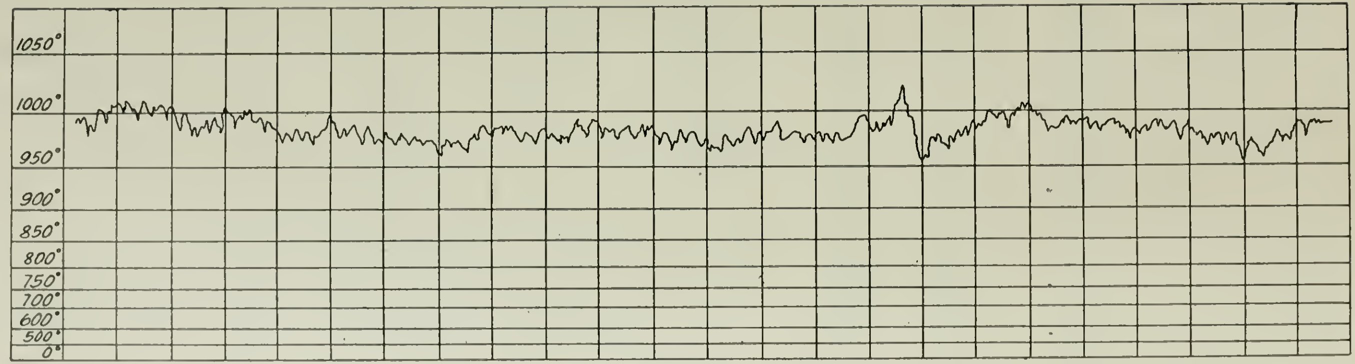


FIG. 26.

TEMPERATURE RECORD FOR 24 HRS. OF A STEEL ANNEALING FURNACE ATTAINED WITH A FÉRY RADIATION PYROMETER AND THREAD RECORDER. MAXIMUM RANGE ABOUT 75 DEGREES.

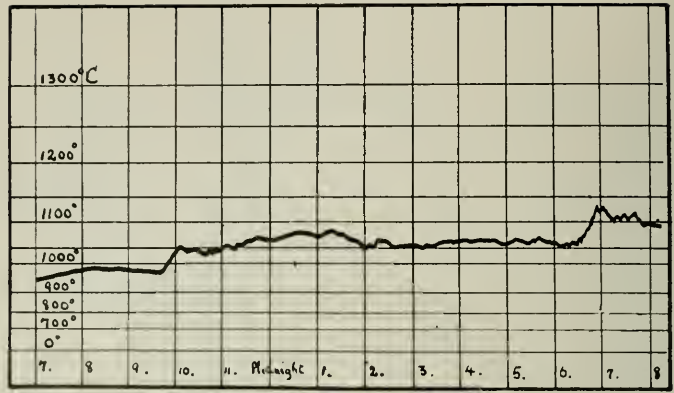


FIG. 27.

RECORD OF THE TEMPERATURE OF A POTTERY "BISCUIT" KILN ATTAINED WITH A FÉRY RADIATION PYROMETER AND THREAD RECORDER.

is approximately a measure of the intensity of the vertical component of the radiation to which they are exposed. It has already been shown with these instruments, that the heat received by reflection from the sky under certain conditions may amount to more than 40 per cent of the whole vertical component. The records have also shown what a large proportion the negative radiation bears to the amount of radiation falling on the earth during the day. The radiation is continually varying throughout the whole night.

These instruments have also been successfully employed to measure boiler radiation, more especially to compare the relative efficiency of various boiler laggings.

CALOMETRIC.—The Siemens water calorimeter is so well known that there is no necessity to describe it in detail. A ball of copper, iron, or platinum of known weight is exposed to the heat of a furnace, and is then transferred to a vessel containing a measured quantity of water at a known temperature. It can readily be seen that, knowing the rise in the temperature of the water, owing to the insertion of the hot body, and the specific heat of the metal ball employed, the temperature of the furnace can be deduced.

FUSION THERMOMETERS—Reference must be made to the excellent work of Seger in producing a series of cones melting at various temperatures by varying mixtures of quartz, sand, felspar, etc., and to the work of Mr. Henry Watkin in the same direction. I should also like to draw attention to an ingenious device invented by Messrs. E. H. Griffiths and W. C. D. Wetham. An iron rod is held rigidly in a steel tube by means of an alloy melting at any given temperature. The rod is free to rotate as soon as the alloy is melted, and can be made to ring an alarm either mechanically or electrically or to shut off gas, steam, etc. By a simple contrivance it can easily be reset for another experiment.

I feel that I have only touched on the fringe of thermometry and its many applications. The number of these applications must increase as the demand for scientific accuracy increases in all our large industries.

The thanks of the Society and of Mr. Whipple are tendered the Armour Institute of Technology and to Professors Gebhardt and Burnham for apparatus loaned for this lecture, and for assistance rendered.

Discussion

Mr. W. C. Robinson—I would like to ask in regard to the durability of the porcelain tubes in the platinum-rhodium Pyrometer when subjected to fire. We have used quite a number and find that they last only about one day. As they cost about seven or eight dollars apiece, their very short life makes them exceedingly expensive, and I am wondering whether a tube is not now made that will prove more durable. I am speaking of the closed end of the porcelain tube. The temperature was from 1,000 to 2,000 deg. Fahr. The tube is about 18 inches in length. I refer to the outside tube, inclosing the smaller tubes, around the wires themselves. The outer tube breaks off at the curved end, which exposes the couple to the gas of the furnace.

Mr. Whipple—Could you not put a steel tube around the porcelain tube?

Mr. Robinson—We have tried that method, but have been criticised for doing it.

Mr. Whipple—It takes off a good deal of the shock of sudden heating and cooling.

Mr. Robinson—We are very careful in taking them out. We calibrate a large furnace by the use of the platinum-rhodium elements, and use for practical purposes a water coil; having a clean fire we take the temperature of the inlet and outlet. The rising temperature, having calibrated it, will give us an indication of the heat in the furnace. We are using that now with some success.

Mr. Whipple—I think it is worth trying, wherever you can, to put the iron sheath on.

Mr. Robinson—In some cases we have wound the wires with asbestos and dropped the whole thing into ⅜-inch gas pipe capped; of course there is a lag; but that method has been criticised owing to the statement that platinum-rhodium would disintegrate and change the e. m. f. from the force generated.

Mr. Whipple—I should not think that would be a good method. The cap is hardly likely to be gas tight and asbestos appears to have a harmful action on platinum. We are now experimenting with some quartz tubes, and the idea looks very encouraging.

A Visitor—I would like to ask if there is a possibility of the Pyrometer being modified so that an ordinary recording instrument of less sensibility can be used with it, using heavier current? Those thread recorders are rather delicate to take into a shop, and the idea would be to use a recorder such as is used for voltmeter work, in which the needle rests on the battery all the time.

Mr. Whipple—We have been considering methods for making a simplified form of recording resistance thermometer but it is not an easy problem. The Thread Recorders have been found to work very satisfactorily even in positions where they were severely handicapped with dust and vibration.

President Arnold—Could you not take an ordinary Pyrometer and dial and provide the dial with a graduated disc as in voltmeter practice, and let the needle carry an indicating pen point? It may be that there is not sufficient strength to operate the needle and overcome the resistance of the pen when traveling on the paper disc.

Mr. Whipple—No there is not strength enough. That is the difficulty; all the electrical forces are so small.

Mr. McMeen—The author has indicated in his paper that the distance of the radiation pyrometer from the heat is of little importance. Does it make a difference what distance exists between the furnace and telescope, and if not, why?

Mr. Whipple—That is difficult to explain. Suppose you take the temperature of a very big hot body—suppose it was infinitely large—then you could go back an infinite distance, but as your body gets smaller, you have to come nearer and nearer, but as long as the heat rays falling on the instrument entirely fill the mirror and the image of the hot body covers the couple, then you are independent of the distance. The image of the hot body overlaps the thermo-junction on all sides, so that where the hot body is approached more nearly, thus increasing the size of the image produced, the only effect is to increase the amount of overlapping, while the thermo-junction receives no more radiation than before.

In practice you ought to have a hot body at least 3 inches in diameter to begin with, and then increase it by an inch for every foot you get away from it; so that if you are looking at a hot body about two yards distant the hot surface should be at least six inches in diameter.

Mr. McMeen—I would ask, from the standpoint of the layman, what relation there is between the Féry Pyrometer, and the so-called optical Pyrometer.

Mr. Whipple—The Féry instrument is a radiation Pyrometer. With it you can take the temperature of a non-luminous body. If you had a sensitive galvanometer you could take the temperature of boiling water; by observing the radiation coming from the water. The majority of optical-pyrometers are really photometers, in which you compare either the luminosity or spectra of the hot body against that of a standard source of light. In all these forms the temperature observation depends largely on the color judgment of the observer.

The only other satisfactory radiation instruments that I know of are the Langley bolometer, the radiometer, and the radio-micrometer designed by Prof. C. V. Boys. In the latter you have a very fine loop of wire hung in a magnetic field, a small thermo-couple being attached to the ends of the loop, the thermo-couple supporting a small blackened disc. The heat is received on the disc, and the current generated, deflects the wire loop. The whole arrangement is so sensitive that you can detect the heat of a candle 1,000 feet off.

Mr. J. H. Warder—Would the Féry Pyrometer be applicable to a steel furnace where they are pouring out a great amount of melted steel? Can you get the radiation from that? It is often well to know what is the difference in temperature between different casts of metal, or know that the temperature of a cast of metal be not too high or too low.

Mr. Whipple—Yes, that is an important application. It has been shown that the strength of a steel casting largely depends on the temperature at which it was poured.

Mr. Warder—How are those variations of the index of the instrument converted into degrees of temperature?

Mr. Whipple—The radiation which passes through an observation hole in the wall of a furnace, for instance, falls upon the concave mirror in the telescope and is thus brought to a focus. In this focus is a thermo-electric couple, whose temperature is raised by the radiation falling upon it; the hotter the furnace, the greater the rise in temperature of the couple. The electro-motive force generated by the couple is measured by a sensitive galvanometer. In practice the pyrometer is standardized by means of an electric resistance furnace. A small diaphragm is placed in the center of the furnace and its temperature is observed either by a standardized Féry Pyrometer or by a thermo-electric couple. The fusing point of a small piece of sheet silver is a valuable standardizing point. The graduation of the galvanometer scale is based on the Stefan-Boltzmann radiation law which expresses the relation between the temperature of a body and the amount of radiant energy which it emits. The law is as follows: "The radiant energy emitted by a black body is proportional to the fourth power of the absolute temperature of the body." Thus knowing the reading on the galvanometer scale for one temperature it is possible to calculate temperatures corresponding to any other readings on the galvanometer scale. In practice the galvanometer scale is divided in milli-volts and temperatures.

Mr. McMeen—What are the relative upper limits of various Pyrometers?

Mr. Whipple—The Féry radiation Pyrometer, theoretically, has no limits. The others have. The limit of thermo-couple is 1,600 deg. cent.; the limit of resistance thermometer is 1,200 deg. cent.

It is difficult to find a protecting tube that will stand more than 1,600 deg. cent.

Mr. McMeen—You say there is no such maximum restriction in the case of the radiation Pyrometer?

Mr. Whipple—No, there is no maximum limit.

CORRECTION

In the paper on Swing Bridges in February issue on page 28, discussion by Mr. C. F. Loweth, first and second lines should read "It is *possible* to make satisfactory swing bridges." Please note and make change in your copy of the JOURNAL.

VIBRATIONS IN PASSENGER TRAINS FROM HIGH SPEED ELECTRIC LIGHTING ENGINES.

F. W. Huels.

Presented December 19, 1906.

The vibrations in passenger trains caused by the reciprocating action of the high speed engine of the electric generating sets constitutes one of the principal objections to their use. These engines produce vibrations that are sometimes of considerable magnitude owing to lack of perfect balance of the reciprocating parts. The vibrations are transmitted back into the train, since the whole train is elastic. Thus a source of annoyance to the passengers is created which railways would be glad to get rid of, and steam turbines are now replacing reciprocating engines in the train lighting field because they have the advantage of no vibration.

It is interesting and of some importance to know something about the magnitude and character of these vibrations. So far as is known to the writer, no attempt has been made, heretofore, to make measurements of them. In the following pages the results of tests of this kind are presented.

METHOD OF LOCATING GENERATING SETS AS ADOPTED BY VARIOUS ROADS.

In Plate 1 is shown the method of locating the generating set as adopted by the Chicago, Milwaukee and St. Paul Railway Company. Here the engine is placed crosswise in the baggage car and as close to the locomotive as possible. This location is at a point about three feet ahead of the forward king bolt. It is claimed that in this way the piping between the locomotive and the lighting engine is reduced to a minimum length, thereby reducing the condensation of steam in the pipe to a minimum.

The Chicago and Northwestern Railway and the Northern Pacific Railway adopt the arrangement shown in Plate 2. Here the generator is placed so that the shaft is parallel to the length of the car and at a point over the rear king bolt. The Chicago and Northwestern Railway uses this system because the front part of the car is the express compartment and the door leading into it is kept locked. By placing the set in the rear of the car, the electrician can attend to it without disturbing the express man. In this arrangement the distance between the locomotive and generator is as much as fifty feet, which produces a considerable amount of condensation in the steam pipe.

Further, it has been claimed that the vibrations could be felt farther back in the train when the latter arrangement is employed because the "vibration center" is farther back in the train. The ex-

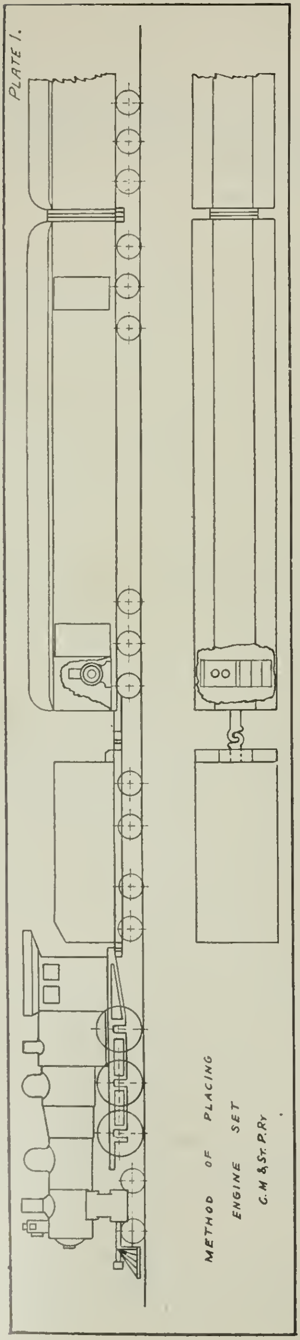
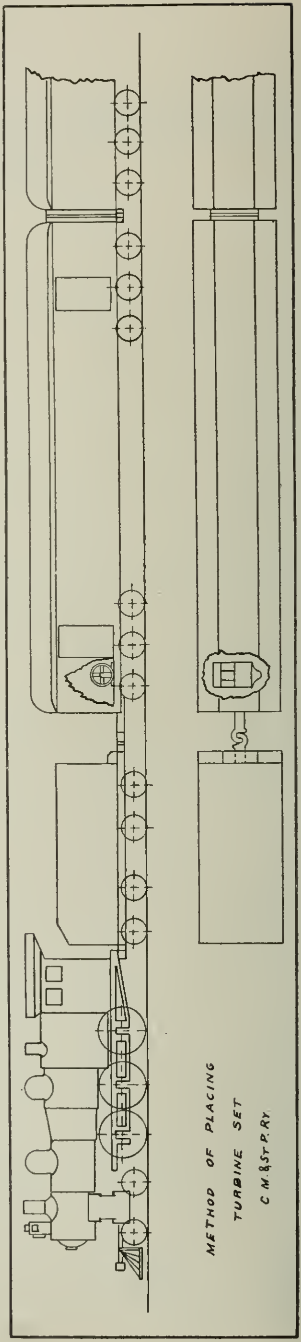


PLATE I.
METHOD OF PLACING
ENGINE SET
C.M.&ST.P.RY


METHOD OF PLACING
TURBINE SET
C.M.&ST.P.RY.

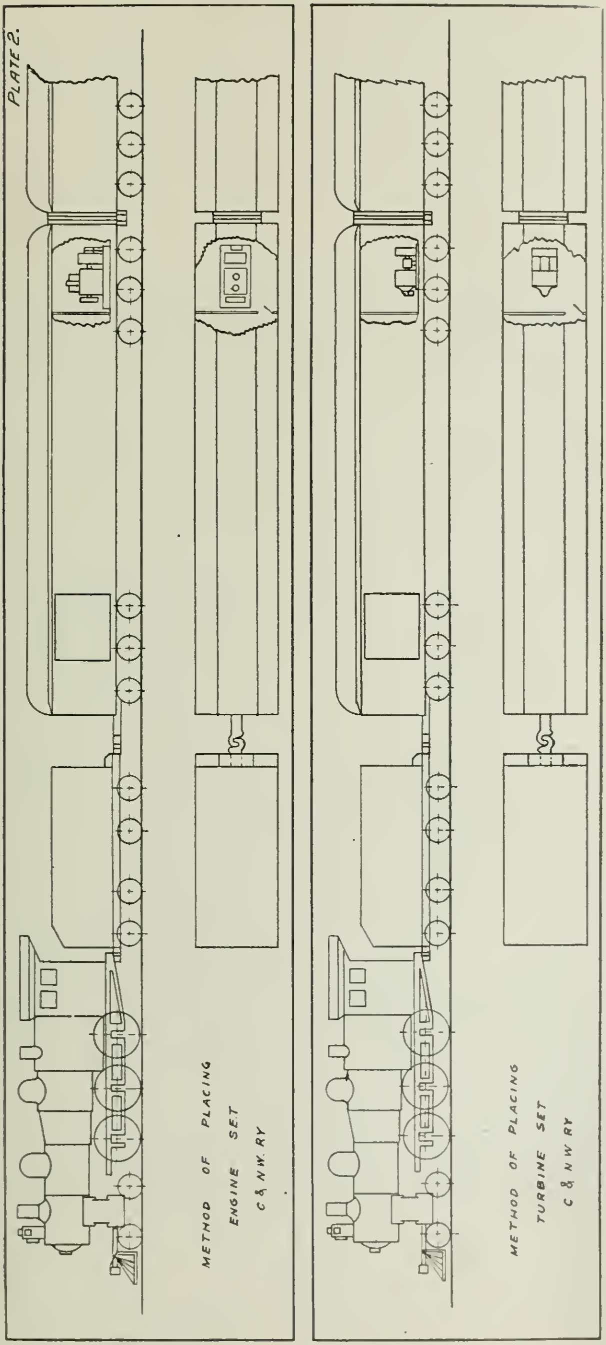


PLATE 2.
METHOD OF PLACING
ENGINE SET
C & N.W. RY
METHOD OF PLACING
TURBINE SET
C & N W RY

periments on vibrations described in this paper seem to bear out this point, as will be observed by making an examination of Plate 9.

VIBRATION INDICATORS AND SEISMOGRAPHS.

For measuring vibrations of this kind, instruments known as "seismographs" or "seismometers" are used. This name was originally given to instruments constructed to measure the movement of the ground during earthquakes. Webster's dictionary gives these definitions:

> "Seismometer: An instrument for measuring the direction, duration, and forces of earthquakes and like concussions."
>
> "Seismograph: An apparatus for registering the shocks and undulatory motions of earthquakes."

One of the types of earth movements that are recognized and of which measurements are made, consists of:

Sudden displacements or "earth tremors," resembling earthquakes in the rapidity with which they take place, but differing from them in that they can be detected only by means of instruments on account of the smallness of the motion.

It can be seen that this class of movements or "earth tremors" resembles the vibratory movements caused by the reciprocating engines of train lighting sets. Hence, instruments used to measure this type of movement will be considered further.

The following notes taken from an article on the "Seismometer" in the Encyclopaedia Britannica show the principles upon which these instruments are based.

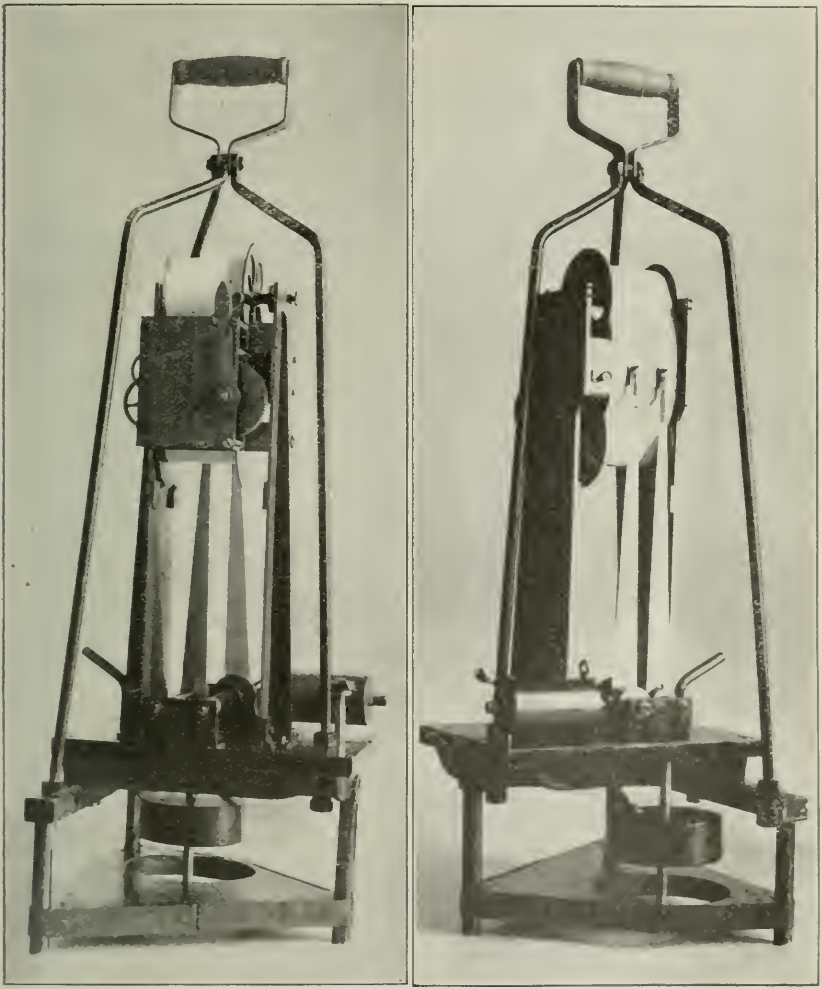
"In the first type of measurements what may be called the 'inertia method' is followed. A mass is suspended with freedom to move in the direction of that component of the earth's motion which is to be measured. When an impulse occurs the supports move, but the mass is prevented by its inertia from accompanying them. It supplies a steady point to be used as a standard of reference in determining the extent through which the ground has moved in the direction in question. . . . In all instruments, designed to furnish a steady point, the suspended mass must have some small stability, else it would be unmanageable; but its period of free oscillation must be greater than that of the earthquake motions which it is employed to measure. . . . The whole movement is resolved into rectilinear components, and these are separately recorded. . . . on a plate or drum which is kept in continuous movement, so that the record of each component takes the form of an undulating line, from which the number, succession, amplitude, velocity, and acceleration of the component movements can be deduced and the resultant motion determined."

THE VIBRATION INDICATOR USED IN THESE TESTS.

The ordinary types of instruments used to measure earthquakes are not suitable for work on railway trains, because they are oversensitive, not portable, nor compact. Something less sensitive, but compact and portable, is required. Consequently, the instrument shown in the following pages was developed. It is a modification of the forms already described. The movement, whatever it may be, is resolved into two components, one vertical and the other horizontal.

The instrument consists of four principal mechanisms which may be described as follows:

1. A mechanism for indicating and magnifying the vertical component of the motion.



REAR VIEW FRONT VIEW

VIBRATION RECORDER

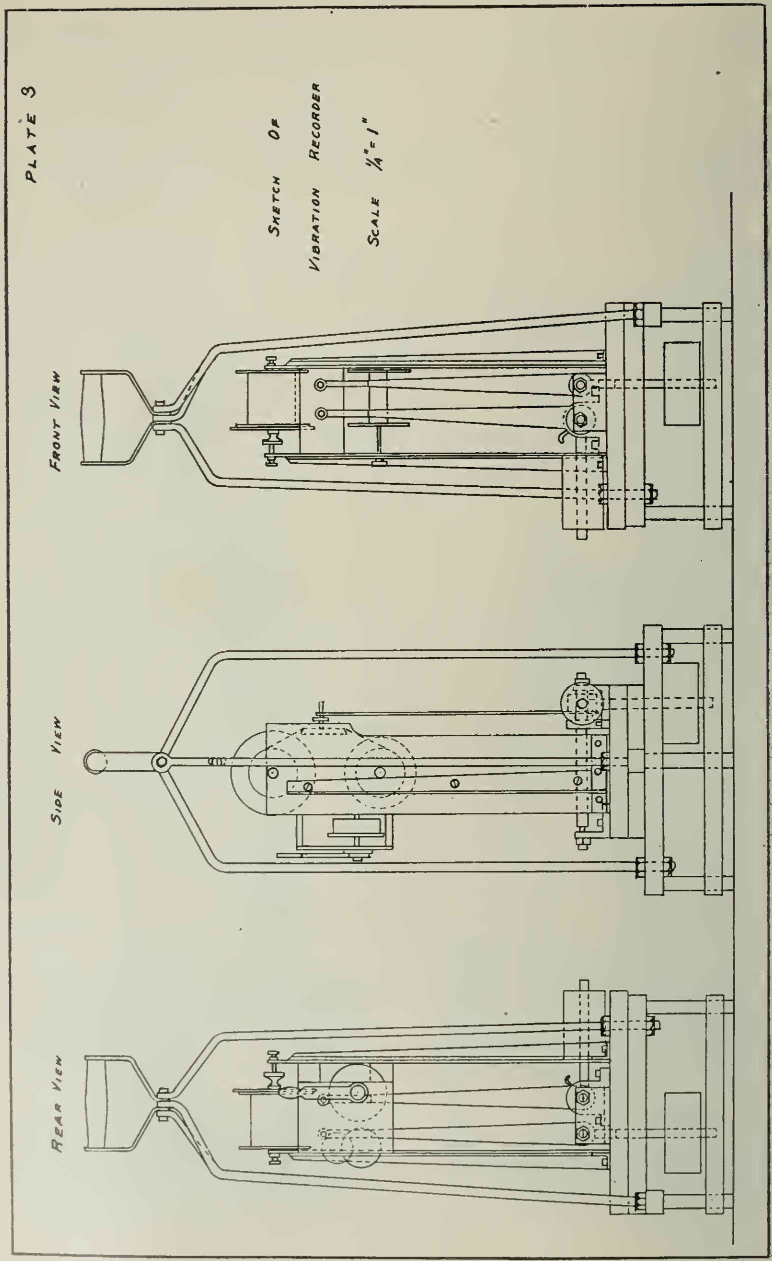
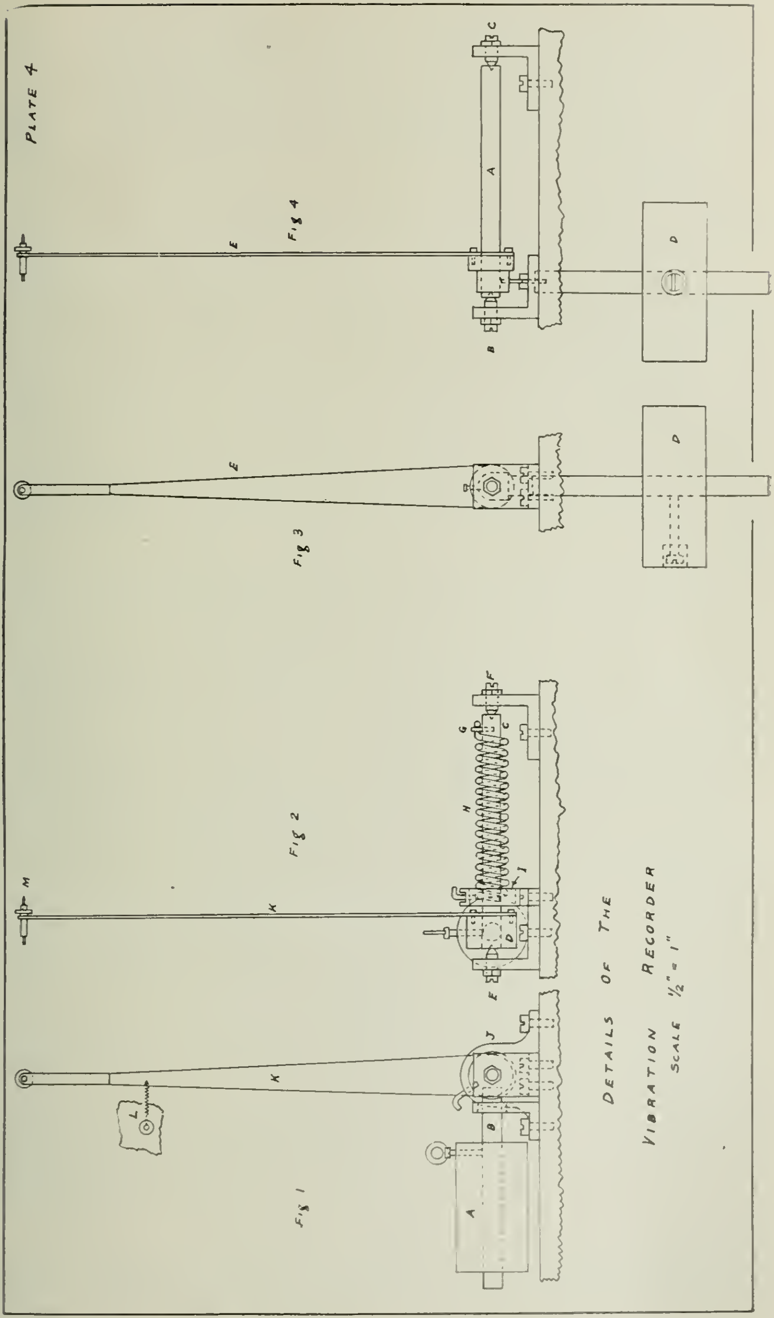


PLATE 3
SKETCH OF
VIBRATION RECORDER
SCALE 1/4" = 1"
FRONT VIEW
SIDE VIEW
REAR VIEW

PLATE 4



DETAILS OF THE VIBRATION RECORDER

SCALE ½" = 1"

2. A mechanism for indicating and magnifying the horizontal component of the motion in one direction.
3. A mechanism for permanently recording both vertical and horizontal components on the same record sheet.
4. A base with suitable framework serving to support mechanisms 1, 2, and 3, and which serves to give stability to the apparatus.

The Vertical Motion—The vertical component of the motion is recorded by the device shown in Plate 4, Figures 1 and 2.

A cylindrical brass weight, A, weighing two pounds, is supported upon the lever, B. The spindle, C, is solidly fastened to B, and at right angles to it, by means of the collar, D. Spindle C is then mounted upon a base by means of the pivots, E and F. At one end of C is the pin. G. Mounted upon C is a coil spring, H, consisting of thirty turns of Number 12 iron wire. One end of this spring is fastened around the pin, G, and the other end is solidly soldered into a collar, I. Collar I fits into the support, J, and is so arranged that the torsion of the coil spring can be regulated. A light aluminum pointer, K, carrying a pencil at its upper end, is mounted upon the collar, D. It magnifies the displacement of the weight, A.

The operation of this device is as follows: When A is moved downward and then released, it returns to its normal position. This normal position is horizontal and it is kept there by placing the proper tension upon the spring, H. When A is moved upward there is a tendency to continue upward. A small spring L may be attached to the pointer, K, its tension being regulated to bring the weight back into its normal position.

Now, for up and down movements of the points, E and F, corresponding to movements of the base of the instrument, some point in A tends to remain stationary on account of the inertia of this weight. As already mentioned, the resulting relative movement is indicated and magnified by the pointer, K, and a record of it is made by the pencil point, M, at the end of the pointer.

It can be seen that a horizontal displacement of the points, E and F, will have no effect upon the weight, A, and will produce no displacement of the pointer, K. Hence, this device records the vertical component of the movements of the base.

The Horizontal Motion—The device by means of which the horizontal motion is recorded is shown in Plate 4, Figures 3 and 4. Such movements are detected by pendulums.

A spindle, A, is pivoted at the points, B and C. Hanging from the spindle, and rigidly fastened to it, is a circular piece of cast iron, D, weighing four and one-fourth pounds. An aluminum pointer, E, carrying a pencil point at its upper end, is also fastened to the spindle.

By examining Figure 3, it will be seen that when the points, B and C, are quickly moved to the right or left, some point in the weight, D, will remain at rest on account of the inertia of the weight. This will cause a multiplied record of the displacement to be made by the pointer, E.

A vertical displacement of the points, B and C, will cause no movement of the pencil point with respect to B and C. Consequently, this contrivance will be unaffected by the vertical component of the motion but will record the horizontal component.

The Recording Mechanism—For permanently recording the vibrations, a strip of metallic paper, two and one-half inches wide, is made to pass under the pencil point by means of clock-work. The paper is unwound from one roller and wound upon another.

Metallic paper and ordinary paper have been used. Brass points, black lead, and indelible copying lead have been used for pencil points. Experience has shown that brass points do not make a satisfactory mark. By using metallic paper and either black lead or indelible lead points a fine record is obtained on the smooth surface of the metallic paper. A further advantage of using indelible points is that the record may be strengthened and permanently fixed by dampening it. This makes a very satisfactory method.

The Base and Framework—These three mechanisms, that for the vertical motion, that for the horizontal motion, and the clock-work for driving the paper, are all supported by the necessary framework upon a heavy iron base. A handle is also provided by means of which the instrument can readily be carried about.

METHOD OF OBTAINING DATA.

The instrument whose characteristics have just been described was set upon the floor of the car under test and allowed to operate. A record was obtained which showed the horizontal and vertical components of the motion of the car floor at that particular point. The instrument, being portable, was next set up on various cars of the train and at various points on the cars.

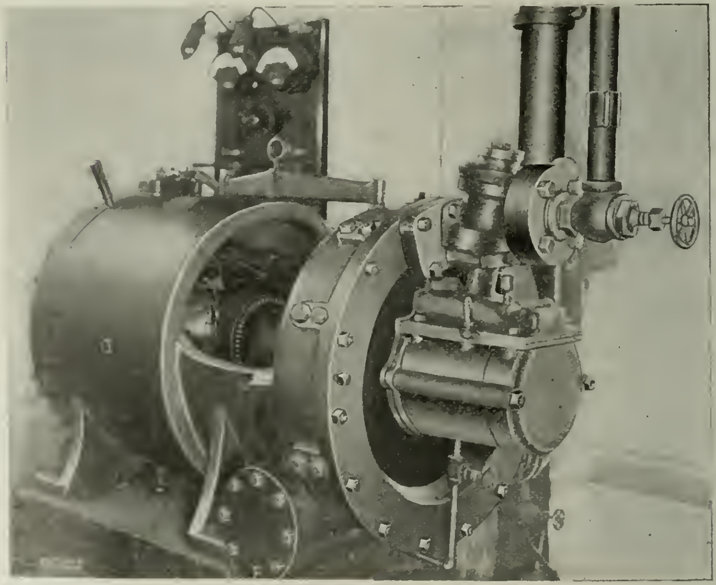
For instance, when a record of the vibration of the baggage car, caused by the lighting engine, was desired, a test was made at the time the train had come to a standstill at some station. The instrument was placed, say, three feet from the generating set, and operated long enough to obtain a record. It has been carried to the center of the car, then to a point above the rear king bolt of the car or to the rear platform, a record being taken at each of these points. Then, if there was time, it was set up in the second, third, and other cars of the train. As a rule, however, the stops are of short duration and it is impossible to obtain more than one record at each stop. It is only at junction points, at points where water is being taken by the locomotive tender, or while standing in the coach yards, that several records can be made. As a result of this the records are not all simultaneous.

TRAINS, CARS, AND SYSTEMS WHICH HAVE BEEN TESTED.

Through the courtesy of the Chicago, Milwaukee, and St. Paul Railway Company, and the Chicago and Northwestern Railway Company, it was possible to make tests of the nature and magnitude of the vibrations produced by the generating sets in use on some of their finest trains. The Chicago, Milwaukee, and St. Paul Railway Company allowed me to make tests on the "Pioneer Limited," an electric lighted train running between Chicago and Minneapolis. Similar tests were made on the "Northwestern Limited" of the Chicago and Northwestern Railway Company, running between the same points. It was thus possible to get comparative results.

Tests were made on Westinghouse "Standard" engine sets and Curtis steam turbine generator outfits on both roads. A summary of these may be given as follows:

1. Pioneer Limited, Chicago, Milwaukee, and St. Paul Railway Company. 20 K. W., Westinghouse Standard Engine and Generator from Milwaukee, Wisconsin, to Tomah, Wisconsin.
2. Pioneer Limited, Chicago, Milwaukee, and St. Paul Railway Company, 25 K. W., Curtis Steam Turbine and General Electric Generator from Tomah, Wisconsin, to Milwaukee, Wisconsin.
3. Northwestern Limited, Chicago and Northwestern Railway Company, 20 K. W., Westinghouse Standard Engine and Generator from Madison, Wisconsin, to Minneapolis, Minnesota, and return.
4. Baggage Car, 216, Chicago and Northwestern Railway Company, 25 K. W., Curtis Steam Turbine and General Electric Generator, standing in coach yards of the Chicago, St. Paul, Minneapolis and Omaha Railway Company, at Minneapolis, Minnesota.



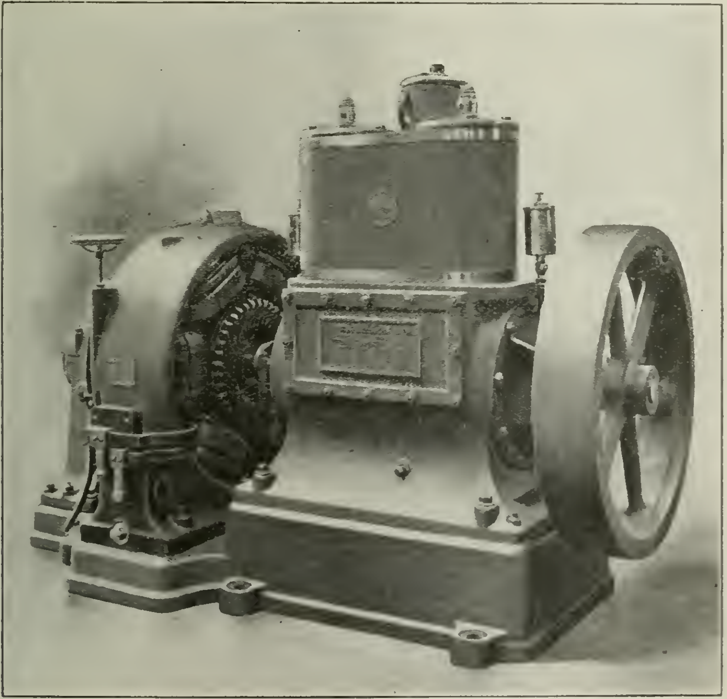
25-K. W. Curtis Turbine-Generator.

RESULTS OF TESTS.

In the following pages are given tables and diagrams showing the results of tests made in the manner just described. These data are largely self-explanatory. The vibration was resolved into its horizontal and vertical components and in the diagrams these are shown by the upper and lower curves, respectively. The number of vibrations per minute, the extent of the vibrations, in inches, and remarks relating to the station, position, and time of the record, are given.

These records were taken on trains that were as nearly alike as possible in all respects. 20 K. W., Westinghouse engines and 25 K. W., Curtis turbines were tested on both trains, the only difference being that the sets in the case of the Chicago, Milwaukee, and St. Paul trains were crosswise and in the front of the baggage car, while, in the Chicago and Northwestern trains they were lengthwise and in the rear of the baggage car.

Plate 9 gives comparative results at various points on the trains. The figures at the top of the records on this sheet indicate the number of the record in Plates 5, 6, 7, and 8.



Westinghouse Engine and Generator Lighting Set.

TABLE I.

TESTS OF VIBRATIONS CAUSED BY A WESTINGHOUSE, 20 K. W., TRAIN LIGHTING SET "PIONEER LIMITED," C. M. AND ST. P. RAILWAY.

May 5 and 6, 1906.

Engine, Number 4245. 7½" × 7". 400 R. P. M. Generator, Number 58538.

	VERTICAL		HORIZONTAL			REMARKS.	
Record Number	Number of Vibrations per Minute	Extent of Vibrations in Inches	Number of Vibrations per minute	Extent of Vibrations in Inches	Station	Position	Time
1	410	0.03	410	0.01	Milwaukee	Baggage car Three feet from engine	9:01 P. M
2	344	0.03	344	0.01	Pewaukee	Baggage car Three feet from engine	9:43
3	377	0.02	377	0.01	Hartland	Baggage car Three feet from engine	9:53
4	322	0.03	322	0.01	Oconomowoc	Baggage car Center of car	10:11
5	396	0.02	396	0.02	Watertown	Baggage car Center of car	10:30
6	None Perceptible		None Perceptible		Watertown Junction	Buffet car Rear platform	——
7	384	0.01	384	0.01	Portage	Buffet car Center of car	11:55
8	405	0.01	405	0.01	New Lisbon	Baggage car Rear of car	1:14 A. M
9	374	0.05	374	0.01	New Lisbon	Baggage car Center of car	1:15
10	386	0,02	386	0,01	Camp Douglas	Baggage car Near generator	1:30

Ba

Re
N

TABLE III.

TESTS OF VIBRATIONS CAUSED BY A WESTINGHOUSE, 20 K. W., TRAIN LIGHTING SET. "NORTHWESTERN LIMITED," C. AND N. W. RAILWAY.

July 20 and 21, 1906.

Baggage Car, Number 1107. Engine, Number 4171. 7½" × 7". 400 R. P. M. Generator, Number 52974.

Rec. No.	VERTICAL		HORIZONTAL		REMARKS.		
	Number of Vibrations Per Minute	Extent of Vibrations in Inches	Number of Vibrations Per Minute	Extent of Vibrations in Inches	Station	Position	Time
16	382	0.03	None Perceptible		Lodi	Baggage car (1107) Three feet from engine	11:19 P. M.
17	388	0.02	388	0.03	Baraboo	Baggage car (1107) Three feet from engine	11:55
18	403	0.03	403	0.06	Reedsburg	Baggage car (1107) Three feet from engine	12:26 A. M.
19	400	....	400	0.06	Elroy	Baggage car (1107) Three feet from engine	1:05
20	400	0.10	400	0.02	Elroy	Baggage car (1107) Three feet from engine	1:10
21	400	0.01	400	0.01	Elroy	Baggage car (589) Center of car	1:12
22	408	0.03	408	0.02	Camp Douglas	Baggage car (1107) Three feet from engine	——
23	390	0.01	None Perceptible		Minneapolis Coach Yards	Baggage car (589) Center of car	7:00 P. M.
24	None Perceptible		None Perceptible			Buffet car (589) Rear platform	
25	390	0.01	None Perceptible			Baggage car (589) Rear platform	
26	None Perceptible		None Perceptible			"Deerfield" Middle of car	
27	390	0.08	390	0.02		Baggage car (1107) Three feet from engine	
28	390	0.04	390	0.02		Baggage car (1107) Middle of car	
29	390	0.02	None Perceptible			Baggage car (1107) Front of car	
30	390	0.08	None Perceptible			Baggage car (1107) Three feet from engine	
31	390	0.02	None Perceptible			Baggage car (1107) Middle of car	
32	390	0.02	None Perceptible			Baggage car (1107) Middle of car	8:00 P. M.
33	390	0.02	None Perceptible			Buffet car Rear platform	
34	None Perceptible		None Perceptible			"Deerfield" Front platform	
35	388	0.06	388	0.02	St. Paul depot	Baggage car (1107) Three feet from engine	8:35 P. M.

TABLE II.

TESTS OF VIBRATIONS CAUSED BY A GENERAL ELECTRIC, 25 K. W., CURTIS TRAIN LIGHTING SET.

"PIONEER LIMITED," C. M. AND ST. P. RAILWAY.

May 5 and 6, 1906.

Baggage Car, Number 410.
Turbine, Number 3229.
Generator, Number 111775.
Steam Pressure, rated, 80 pounds per square inch.
Amperes, 200; Volts, No load, 120; Full load, 125.

REMARKS.

Rec. No.	Station	Position	Time
11	Camp Douglas	Baggage car Three feet from engine	2:37 A. M.
12	New Lisbon	Baggage car Three feet from engine	2:43
13	New Lisbon	Baggage car Center of car	2:51
14	Portage	Baggage car Center of car	4:00
15	Watertown Junction	Baggage car Center of car	5:25

TABLE IV.

TESTS OF VIBRATIONS CAUSED BY A GENERAL ELECTRIC, 25 K. W., CURTIS TRAIN LIGHTING SET.

CHICAGO, ST. PAUL, MINNEAPOLIS AND OMAHA RAILWAY.

July 21, 1906.

Baggage Car, Number 216.
Turbine, Number 2907.
Generator, Number 111715.

REMARKS.

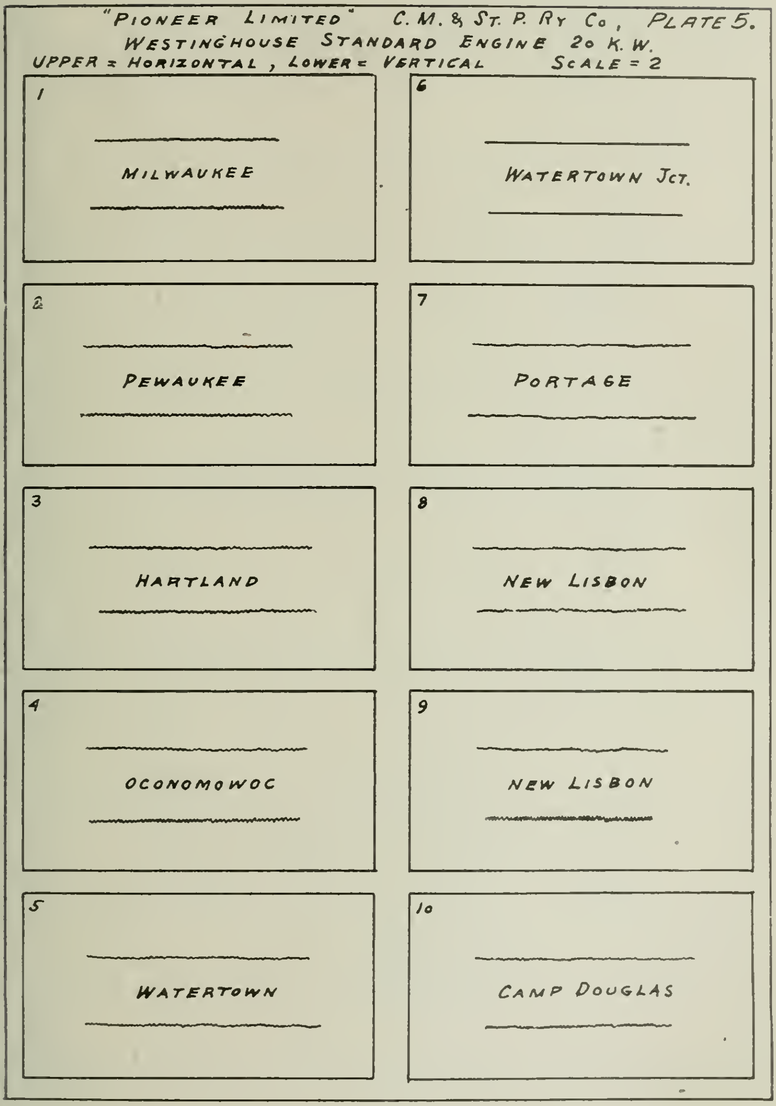
Rec. No.	Station	Position	Time
36	Minneapolis Coach Yards	Baggage car Next to generator	6:30 P. M.
37		Baggage car Next to generator	
38		Baggage car Next to generator	
39		Baggage car Center of car	
40		Baggage car Center of car	

RESUME.

From the experiments recorded in this paper and from general observations it appears that reciprocating engine train lighting sets, as installed at present, produce vibrations of considerable magnitude, due to unbalanced forces set up in them by the reciprocating motion of their parts. Many of you, no doubt, have experienced them while traveling upon electric lighted trains. The waves of vibration thus produced are transmitted back into the train for a distance which depends to some extent not only upon the method of placing the generating set in the car and its position in the train but also upon the nature and condition of the coupling, buffing, and vestibuling devices. Other factors, some of which are pointed out in what follows, influence the extent of the vibratory waves and the distance of their transmission. The vibration becomes apparent when the train is at rest, but as soon as the train starts and when under way the pitching and tossing of the cars is great enough to destroy the effect of the vibrations caused by the lighting set. It appears from the records that the vibrations produced are of a complex character, and that they can be resolved into components. In this work the vibration of the car floor was resolved into vertical and horizontal components, the horizontal component being determined longitudinally in the car. There is also a lateral horizontal component of the vibration but it is not recorded in this paper since it is of small extent and often absent. Thus, the car vibrates in three dimensions. The component vibrations appear to have a "peaked" wave form and where both components exist there are as many horizontal as there are vertical vibrations.

The vibration frequency is in the neighborhood of 400 per minute and, since the lighting engines run at this speed, it may be said that there is one vibration per revoluton of the electric light engine. Or, what is the same thing, there are as many vibrations as there are revolutions. Hence, the number of vibrations depends upon the speed of the lighting engine.

The extent of the vibration is greater in some parts of the car than in others. The minimum vibration seems to be found at the points of support of the car floor—the king bolts. The vertical vibration is nearly always greater than the horizontal vibration, but exceptions to this have been observed. Thus, the maximum vertical displacement shown on the vibration records is 0.05″ in the Chicago, Milwaukee and St. Paul tests and 0.10″ in the Chicago and Northwestern tests. The maximum horizontal displacement as shown on the records is 0.02″ in the Chicago, Milwaukee and St. Paul tests and 0.06″ in the Chicago and Northwestern tests. This displacement of 0.06″, however, is an exceptional case. Since the vibration recorder magnifies the vibration two-fold, the actual vibration is one-half of the amount indicated by the figures. It is quite probable that the real displacement is somewhat greater than this


"PIONEER LIMITED" C. M. & ST. P. RY CO, PLATE 5.
WESTINGHOUSE STANDARD ENGINE 20 K. W.
UPPER = HORIZONTAL, LOWER = VERTICAL SCALE = 2
1
MILWAUKEE
6
WATERTOWN JCT.
2
PEWAUKEE
7
PORTAGE
3
HARTLAND
8
NEW LISBON
4
OCONOMOWOC
9
NEW LISBON
5
WATERTOWN
10
CAMP DOUGLAS

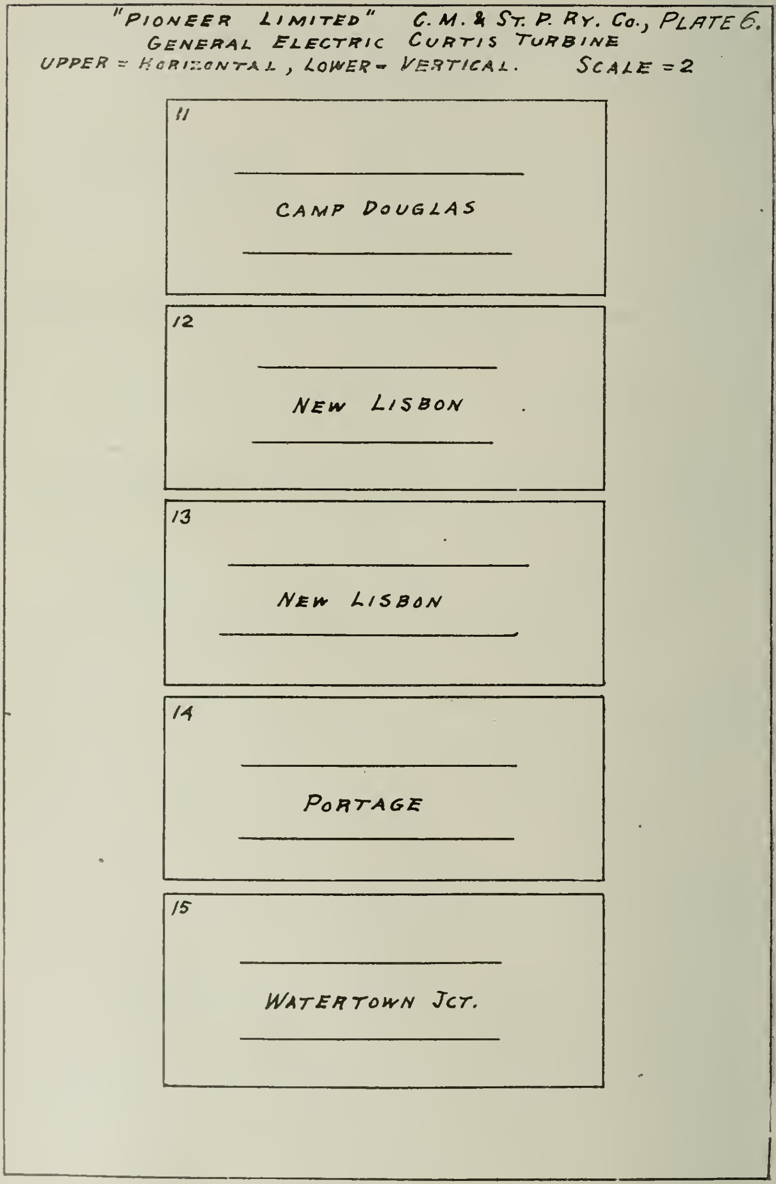
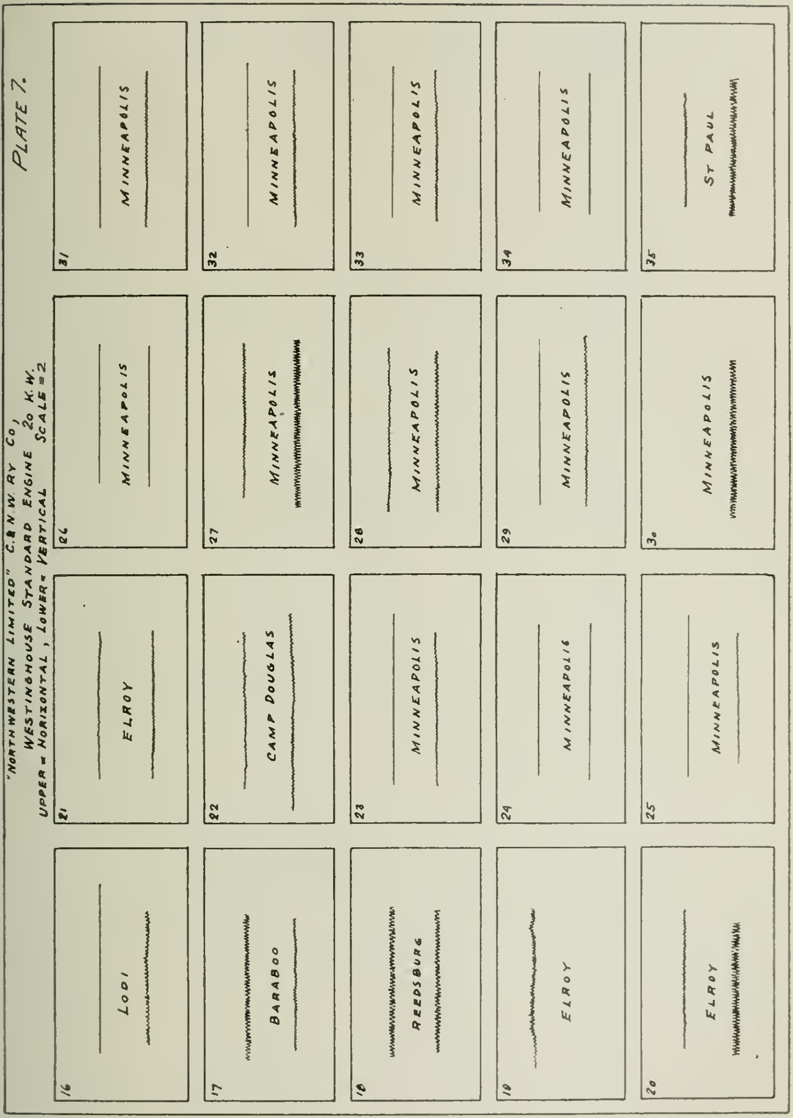
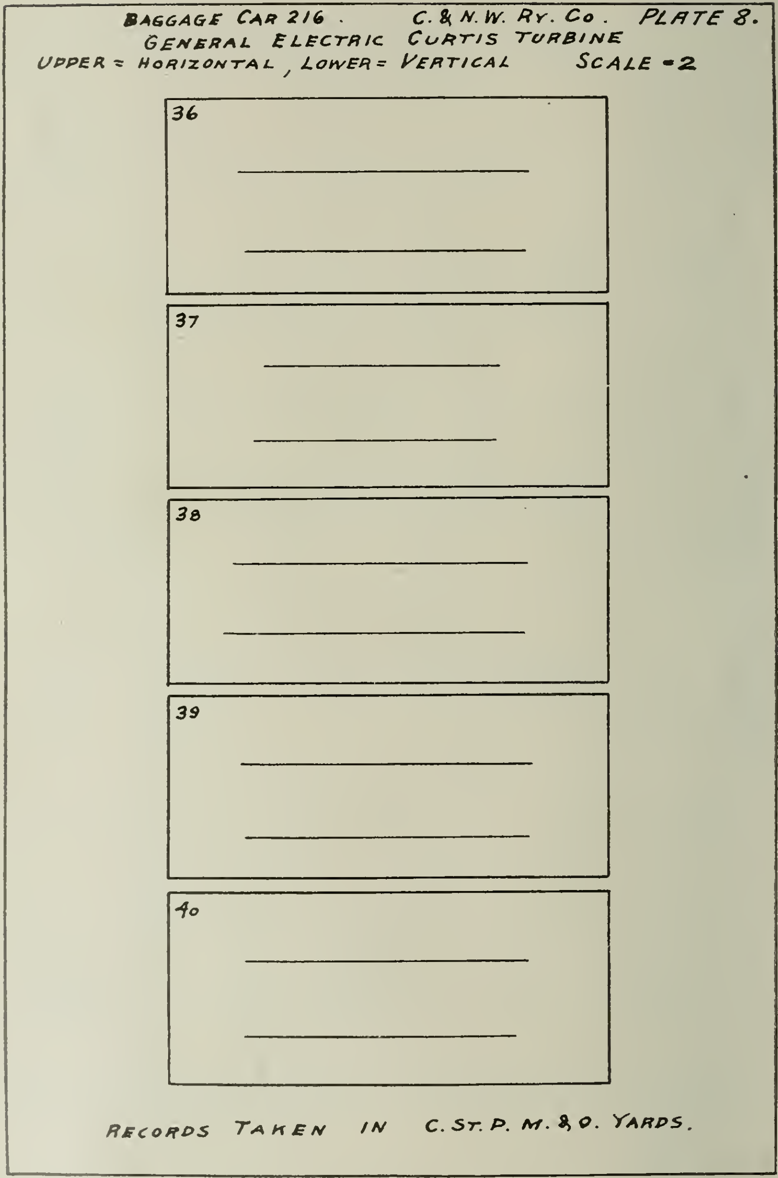

"PIONEER LIMITED" C. M. & ST. P. RY. CO., PLATE 6.
GENERAL ELECTRIC CURTIS TURBINE
UPPER = HORIZONTAL, LOWER = VERTICAL. SCALE = 2
11
CAMP DOUGLAS
12
NEW LISBON
13
NEW LISBON
14
PORTAGE
15
WATERTOWN JCT.

PLATE 7.

"NORTHWESTERN LIMITED" C. & N. W. RY CO,
WESTINGHOUSE STANDARD ENGINE 20 K.W.
UPPER = HORIZONTAL, LOWER = VERTICAL SCALE = 2




BAGGAGE CAR 216. C. & N. W. RY. CO. PLATE 8.
GENERAL ELECTRIC CURTIS TURBINE
UPPER = HORIZONTAL, LOWER = VERTICAL SCALE = 2
36
37
38
39
40
RECORDS TAKEN IN C. ST. P. M. & O. YARDS.

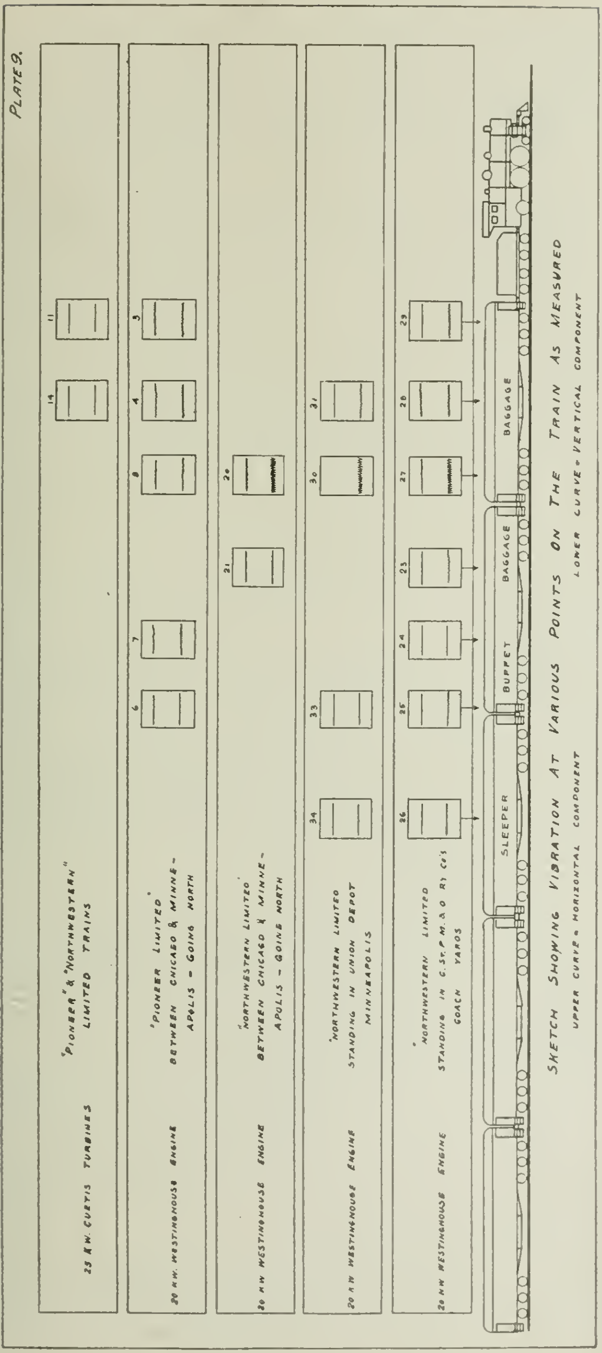


PLATE 9.
25 K.W. CURTIS TURBINES
"PIONEER" & "NORTHWESTERN" LIMITED TRAINS
14
11
20 K.W. WESTINGHOUSE ENGINE
"PIONEER LIMITED" BETWEEN CHICAGO & MINNEAPOLIS - GOING NORTH
6
7
8
4
3
30 K.W. WESTINGHOUSE ENGINE
"NORTHWESTERN LIMITED" BETWEEN CHICAGO & MINNEAPOLIS - GOING NORTH
21
20
20 K.W. WESTINGHOUSE ENGINE
"NORTHWESTERN LIMITED" STANDING IN UNION DEPOT MINNEAPOLIS
34
33
30
31
20 K.W. WESTINGHOUSE ENGINE
"NORTHWESTERN LIMITED" STANDING IN C.ST.P.M.&O. RY CO'S COACH YARDS
26
25
24
23
27
28
29
SLEEPER
BUFFET
BAGGAGE
BAGGAGE

SKETCH SHOWING VIBRATION AT VARIOUS POINTS ON THE TRAIN AS MEASURED

UPPER CURVE = HORIZONTAL COMPONENT LOWER CURVE = VERTICAL COMPONENT since the friction of the instrument absorbs some of the energy of the vibrations.

The buffers and vestibule plates transmit the vibrations from one car to the other, but as the cars are not rigidly coupled together, the energy of the vibrations is largely lost in the flexible joints. The vibration is greatest in the vicinity of the lighting set and becomes less as the distance from the set increases. In other words, some parts of the train vibrate more than others, the most vibration being found at the front end of the train and least at the rear of the train. The tremblings can be detected in the third and sometimes in the fourth and fifth car from the generating set, depending upon conditions.

The amount of vibration depends upon the manner in which the train comes to a stop. When the train comes to a stop with the buffers and vestibule plates tight together, much vibration is felt in the train, but when the buffers and plates are loose, less vibration can be detected. This is shown when the train comes to a stop on a grade. If the grade is down, the cars press against each other and put the buffers and plates into intimate contact. The result of this condition is that the vibration is quite noticeable. If the grade is up, the cars tend to separate, the buffers and plates are not in close contact and a small amount of vibration is transmitted back into the train.

Similar conditions arise when water is being taken at a station. When the engine is "spotted for a water tank," it must be brought into position carefully. If the engineer gets the tender too far ahead of the water spout he backs up a trifle, thereby, "bunching" the train and putting the buffers and plates into intimate contact. This condition makes the vibrations strongly perceptible. On the other hand, if the tender stops too far back of the spout, he goes forward a trifle, thus loosening the contacts. A small amount of vibration is then transmitted.

Another point, in this connection, is that as soon as the train comes to a stop vibrations are felt. But, in starting up again, as soon as there is a pull on the drawbar and before the locomotive driver wheels have made a quarter turn, the vibration disappears. At the instant of starting the buffers are pulled apart so that the vibrations are not readily transmitted.

The weight of the train, the weight of the cars, and the weight of the load have an effect on the magnitude of the vibrations. This is apparent, since it takes more energy to shake a heavy load than it does to shake a light one. Having given an engine set whose impulses produce vibrations of a certain magnitude on light cars, it is probably safe to assume that the same engine will produce vibrations of smaller size on heavier cars.

The size of the reciprocating unit enters into the question. The moving parts of a large unit, being larger, will produce greater disturbing forces, and, for a given weight of car, will produce larger vibrations than a smaller unit. For instance, the records in this paper show that the vibrations can be detected as far back as the third car from the locomotive for 20 Kilowatt Westinghouse sets. In February, 1906, while the train was standing in the Chicago, Milwaukee and St. Paul depot at Minneapolis, the vibration was barely perceptible without instrumental means in the fifth car from the locomotive, a 25 Kilowatt, Westinghouse set being in use at this time.

The records plainly show that the trains equipped with turbine lighting sets are exempt from the annoying vibrations which are likely to traverse a train from a reciprocating engine set.

Aside from the vibratory effect of these lighting sets, noises are produced which are annoying at times. With the Westinghouse set, when the steam pressure is low, a knocking or pounding of the engine takes place when under load. This noise is transmitted back into the train for a considerable distance. The speed (400 r. p. m.) is low enough so that each separate knock can be heard. With the turbine set, a humming or buzzing sound is observed. The higher speed of the turbine (3,600 r. p. m.) makes a noise characteristic of high speeds.

BIBLIOGRAPHY.

1. "On the Vibratory Movements of Locomotives, and on Timing Trains and Testing Railway Tracks."
Paper by John Milne and John McDonald. Minutes of the Proceedings of the Institution of Civil Engineers, Vol. CIII, 1890-1891, Part I, page 47.
2. "Vibrations and Engineering." Engineering, March 13, 1896, pages 339 to 398.
3. "Vibration Meters." Engineering, May 22, 1896.
4. "Bridge Vibrations by Passing Trains." Engineering, April 19, 1895, page 502; January 24, 1896, page 111.
5. "Seismographs." Nature, Vol. 34, page 343.
6. "Vibrations of Engine Foundations." London Electrical Review, July 17, 1896, (serial).
7. "Vibrations in High Speed Engines." London Electrical Review, July 31, 1896.
8. "Vibrations in High Speed Engines. London Electrical Review, April 3, 1896.
9. "Seismometer." Encyclopedia Britannica, Vol. 21, page 627.
10. "Seismometer." Americanized Encyclopedia Britannica, Vol. 9, page 5323.
11. "Seismometer." Chamber's Encyclopedia, Vol. 9, page 303.
12. "Counterweights for Large Engines." D. S. Jacobus, Engineering News, Vol. 53, page 659. June 22, 1905. Transactions of American Society of Mechanical Engineers, 1905.
13. "Earthquakes." J. Milne, (book).
14 "Seismology." J. Milne, (book).

DISCUSSION.

Mr. W. L. Abbott (M.W.S.E.), Chairman—One thing that impressed me while listening to the paper is that passengers on a train are not discommoded nor annoyed by the tossing and pitching of the train incident to traveling over rough roads and around curves, but the instant that the train stops they detect at once a slight tremor, in amplitude, as I understand from the paper, of 1-32 in. It is possible that when the train is moving the vibrations might be as great as 3 in. in an extreme case, without being particularly disturbing. Possibly this is because those vibrations are not regular, and for that reason are not noticed to any extent, but when the train comes to rest, and all other motions cease, the vibrations continue in an isochronous manner, some 400 vibrations a minute and only 1-32 in. in an extreme case; it is very noticeable and annoying. It occurred to me that if these electric lighting engines were set with the crank shaft crosswise of the car—and some of them appear to be so—the vibrations transmitted to the train would be lengthwise and would consist in tightening and slackening the draw bar spring, and I would expect that it would not be transmitted at all, and if at all, very little. In that case (if that were true) I would suppose they would set their engines that way.

However, the advent of the steam turbine has relieved the situation entirely, as a turbine is better adapted for such work than a reciprocating engine. I presume that that is the prime mover which is being installed now on such trains.

The subject of this paper is one of interest to those who are concerned in the refinements of first class train service, which requires the removal of all possible annoyances which might disturb the high priced passengers in the Pullman cars. I notice that those who ride in the smoking car get the greatest shaking up, and therefore it is not as bad as though they had the baggage car in the midst of the sleeping cars.

Mr. J. H. Warder (M.W.S.E.)—What fixed the element of the weights you used that by their inertia give the vibration to those pointers, which were recorded on the paper? Was there any particular determination as to what those weights should be?

Mr. Huels—That weight was not pre-determined. The weights used in the machine were tried and found to do what was required.

Mr. Warder—What is that metallic paper? Is it the same as is used with steam indicators, with a smooth coated surface?

Mr. Huels—Yes, the same thing; it has a very smooth surface on one side, and you can make a mark on it with a metallic point such as silver or brass. The reason we use a metal point is. it does not break off or wear out as rapidly as other kinds.

Mr. E. C. DeWolfe (M.W.S.E.)—We used to have to pay high prices for that metallic paper. I recently discovered that it is nothing more than a good quality of glazed paper such as is used in a fine catalogue, and can be had from the paper dealer at much cheaper rates than formerly.

In regard to those vibrations, Mr. Abbott spoke about the generating set being placed crosswise, as in the St. Paul practice, throwing a longitudinal vibration. I was wondering whether the instrument was set the same way for both systems; that is, in the Northwestern test was the instrument set to read a transverse vibration on account of the generating set having its axis lengthwise of the train, and in the St. Paul set the other way?

Mr. Huels—The object was to get comparative results; the instrument was set up the same way on both trains.

I always observed one way of setting the recording instrument in relation to the length of the car, whatever might be the method of placing the generating set in the baggage car. The horizontal motion was lengthwise of the train.

Mr. Abbott—Is that the objectionable motion?

Mr. Huels—No, the objectionable motion is up and down.

Mr. Abbott—Is the crosswise motion objectionable?

Mr. Huels—There is very slight vibration from the crosswise motion. I found, after making a few observations, that what we call a crosswise movement of the train was so small I could not record it, and I paid no atttention to it after that, simply taking the vertical vibration and horizontal vibration in the longitudinal direction of the train.

Mr. E. P. Marsh—The matter of vibrations on passenger trains was something which developed after the idea of furnishing electric light on trains was suggested, and on some roads an endeavor to minimize the vibration was attempted by using a special spring draw bar carrier yoke, as the vertical vibration is transmitted chiefly through the draw bar pull, and by use of this spring yoke it was endeavored to remedy at least a part of this vibration. The choice of position of the various sets sometimes varies for different reasons than have been suggested by the author. For instance, on the Northwestern road the chief reason for carrying the outfit on the rear end of the car is that the outfits are quite valuable; in case an accident occurs, and the tender comes back through the baggage car, if the outfit is at the forward end of the car the outfit is lost; if on the rear end, it is more likely to be saved.

Mr. Huels—I was wondering why the Northwestern road thought more of its generating sets than the comfort of the passengers. The St. Paul road sets its machines in a reverse position to that of the Northwestern road.

Mr. Marsh—The Northwestern road has lost one outfit just that way. On new equipments, however, the turbine type is used exclusively, and a large number of axle light outfits are being applied, which have given no trouble in the way of vibration.

Mr. W. E. Symons—I have been much interested in this very valuable and interesting paper of Mr. Huels', as it has brought to my mind a number of points in connection with train lighting, and vibrations, some of which I had reviewed some years ago; others have been made clear to me, that had not occurred to me before.

Some eight years ago, I was in charge of the mechanical department of a system of railways in the south, and was located at Savannah, Ga. We participated in the operation of what was called the "Flordia Limited Train" from New York City to St. Augustine and Port Tampa, and handled by the Pennsylvania Railway; Richmond, Fredericksburg and Potomac Railway, the Atlantic Coast Line and the Plant System, the Plant System having the majority of the mileage. Of course, it fell to us to stand the greater part of the responsibility and expense. Electric lighting was intrduced about that time pretty generally on through trains, and the question of the vibrations, described and analyzed in Mr. Huels' paper, came up. At first it seemed, from the reports we had, that it was something serious; the complaints coming principally from people of wealth and refinement who lived in luxury, and were accustomed to having things made comfortable for them; therefore, the vibrations of the train annoyed them a great deal, and while I was not prepared to conduct any such series of tests, as described by Mr. Huels, yet I made some practical tests in the way of taking actual measurments of the movements of the car body when standing still, with the lighting equipment in movement or operation by placing some fixed gauges in contact with the car, and then measuring the vibrations that actually occurred. I discovered, as a result of these observations, that the vibrations were practically as outlined in Mr. Huels' paper, possibly a little greater. The movement was about 1-16 in. That average was taken from a combination baggage and express car, with the lighting equipment in the front extreme corner, not over the king pin, and not in the center of the car; therefore, it gave the car what might be called a tilting motion in addition to the regular vibrations, that came from the equipment itself, and that was transmitted back through the train quite perceptibly. But in following my tests through the cars, that were attached to this head car, I discovered that the actual movement of the car became almost nil, but the noise was very pronounced. The proposition therefore resolved itself into this, that while there was a noticeable, and to some, a disagreeable *noise*, the vibrations were too slight to have caused any real discomfort; as a rule the pasengers were not disturbed as much as they really imagined they were.

Sometimes in hotels or large buildings, very perceptible vibrations are observed, and one might think that the building was in danger, when in reality it is frequently caused by vibrations from some light, high speed machinery fastened to, or in some manner connected to the walls. In connection with the train investigations and as an experiment, I took one car and moved the equipment to the center of it, and found that the vibrations were very much reduced. Following that, I changed the foundation arrangement, setting the engine bed on a number of helical or spiral springs, placing a yoke over the engine bed and fastening to the car floor, so that in train movement there would be no danger of the engine being thrown from its position. When the equipment was in service under these conditions, there were scarcely any vibrations whatever; they were almost entirely eliminated, although the noise was just as perceptible in the rear car, as when bolted to the car floor. Some of the passengers who complained of the noise did not know the difference.

Investigation of vibrations in a brick building, where the walls seemed to be effected as shown by the mortar crumbling and working out in the form of dust, I assumed that the mortar was not of the best quality; the vibrations were so pronounced as to interfere with desk work in the building.

I went into the basement, and found a little high speed electric light engine fastened to a concrete floor, which was connected to the building walls, thus forming a perfect conductor, and transmitting these vibrations through the walls, and which were in places gradually undergoing a process of deterioration; in my opinion in time this would have affected the safety of the building. In connection with this, I recommended that they apply the same remedy, which gave such good results with train vibration; they did so, and after that, one could hardly discover there was any machinery working in the building, so far as vibrations were concerned.

There is another point, that I wish to mention in connection with train vibrations, and that is, if the author of this paper would carry this matter still further, to the extent of taking a record of the vibrations of both passenger and freight trains in movement, due to the component of undulating or imperfect roadway and speed, it would be very valuable to railway companies; it would determine, to a great extent, the cause of many derailments and accidents that are now simply passed by as "cause unknown."

This is a subject that has not infrequently been broached to railway managers. Some are favorable to its introduction; others again, I presume, may think it might reveal certain track conditions which they do not want made known.

In my opinion some tests as these would be very valuable in connection with railway operation, as the subject seems to present a broad and inviting field of practical experiment with some scientific research.

Mr. Huels—The reason I made these experiments, is because a number of students at the University of Wisconsin were testing some of these lighting sets; we tried to make some kind of a comparison between the different outfits to find out which would be the better for any given condition. We tested for steam economy and found that the turbine sets take a great deal more steam than the Westinghouse sets. So I thought it would be very interesting and possibly afford some means of comparison to get vibrating observations graphically. You have the turbine, taking more steam but having no vibration and hardly any noise, and there are these high speed vertical reciprocating engines, taking less steam and giving more vibration; when the steam pressure is low there is considerable noise. There are other factors that come in, in choosing a lighting set besides vibrations and steam economy. As you all know, the steam turbine does not require any cylinder oil. I do not mean in the bearings, but inside of the moving parts no oil is required, and of course that is a factor in the economy of operation.

In regard to Mr. Symons' suggestion, that the matter of tests be carried further, "to the extent of taking a record of the vibrations of both passenger and freight trains in movement, due to the component of undulating or imperfect roadway and speed," and in that way determine irregularity of roadbed, I have looked into this matter to some extent, and came across some articles on tests of this kind. I noticed that the results of these tests were not altogether satisfactory when made on English railways. I found no record of such tests made on American railways.

My machine was built to measure these very small vibrations—not more than 0.10 in. from the record—while the vibration of a car body is so much greater than that, it shakes my machine all to pieces. I have some blue prints showing what it did with this machine on roadbed. They are not perfect records by any means, and perhaps not accurate.

I have sme records of a car coming to a stop at a railway station and starting up again, showing the effect of braking. I regret that I have not more time to work up such tests as these, but am sure those roadbed tests would bring out many points of interest.

The article on tests made in England (referred to) brought out the fact that in passing over a certain piece of roadbed a peculiar shaking appeared on the record. The railway people went out and inspected the roadbed but could find nothing the matter with it; then they started digging, and found that the ties were all rotten; they could put a pick right through them; although in looking at them from the outside, the top appeared to be in good shape. A good many things could be brought out on the records taken on the run of a train. One of those machines could be put in a car and locked up, and in that way an automatic record could be gotten of the whole trip; you could tell when an engineer started the train and when he stopped; if the train was late—why? A new record could be put in for every trip. In this way one could tell a good deal about the operation of the road. It seems to me that information of that kind would be very valuable.

Mr. Warder—Do you see any difficulty in modifying your machine so that it would be suitable to carry out the idea of Mr. Symons, to record the condition of the track, etc.?

Mr. Huels—Perhaps this particular machine could not be modified, but I think such a machine could be made. I have some references to some articles in different engineering periodicals on machines actually used for that purpose, although I am not able to judge just what a railway operating man would want.

Mr. Symons—In making practical tests for the purpose of determining the flange resistance of car wheels against the rails when rounding curves due entirely to the curvature, a plan has been found at times reasonably accurate, wherein pieces of pig lead are placed on either side of the draw bar shank of sufficient dimensions to fill the space between the draw bar shank and the filler block on either side; this while the cars are standing on a tangent and properly coupled. The train is then pulled around a curve of a certain known degree of curvature, which, of course, results in the pieces of lead being mashed, or flattened in proportion to the amount of pressure against them; after rounding the curve, and coming on to a tangent, or straight track, these pieces of lead are removed, taken to the laboratory, where similar sized pieces, or duplicates, are subjected to pressure in a hydraulic machine with a recording gauge, and when they have been compressed or reduced, the same as the pieces removed from the car, the gauge will indicate a pressure equal to that of the wheel flanges against the rail when the cars were rounding curves; we can, by this method, figure very closely as to the extent of pressure resulting from curvature, and learn much as to the cause and effect of flange wear, rail wear, spreading of rails, and other features in connection with the design, construction, and maintenance of car wheels, trucks and rails on which they run. This method would not clearly indicate the cause of derailments, or the breaking of flanges on car wheels, for the reason, that it does not include the component of all the forces resulting from curvature, speed, centrifugal force, rolling of cars due to rough or undulating track, etc., which all have more or less bearing on the question. It very clearly indicates the pressure against the outer rail when rounding a curve at a slow rate of speed, and it also serves as a guide whereby the engineer, or car builder, can determine what is a sufficient amount of flexibility to be allowed or provided for with cars of certain lengths for rounding curves of a certain degree of curvature.

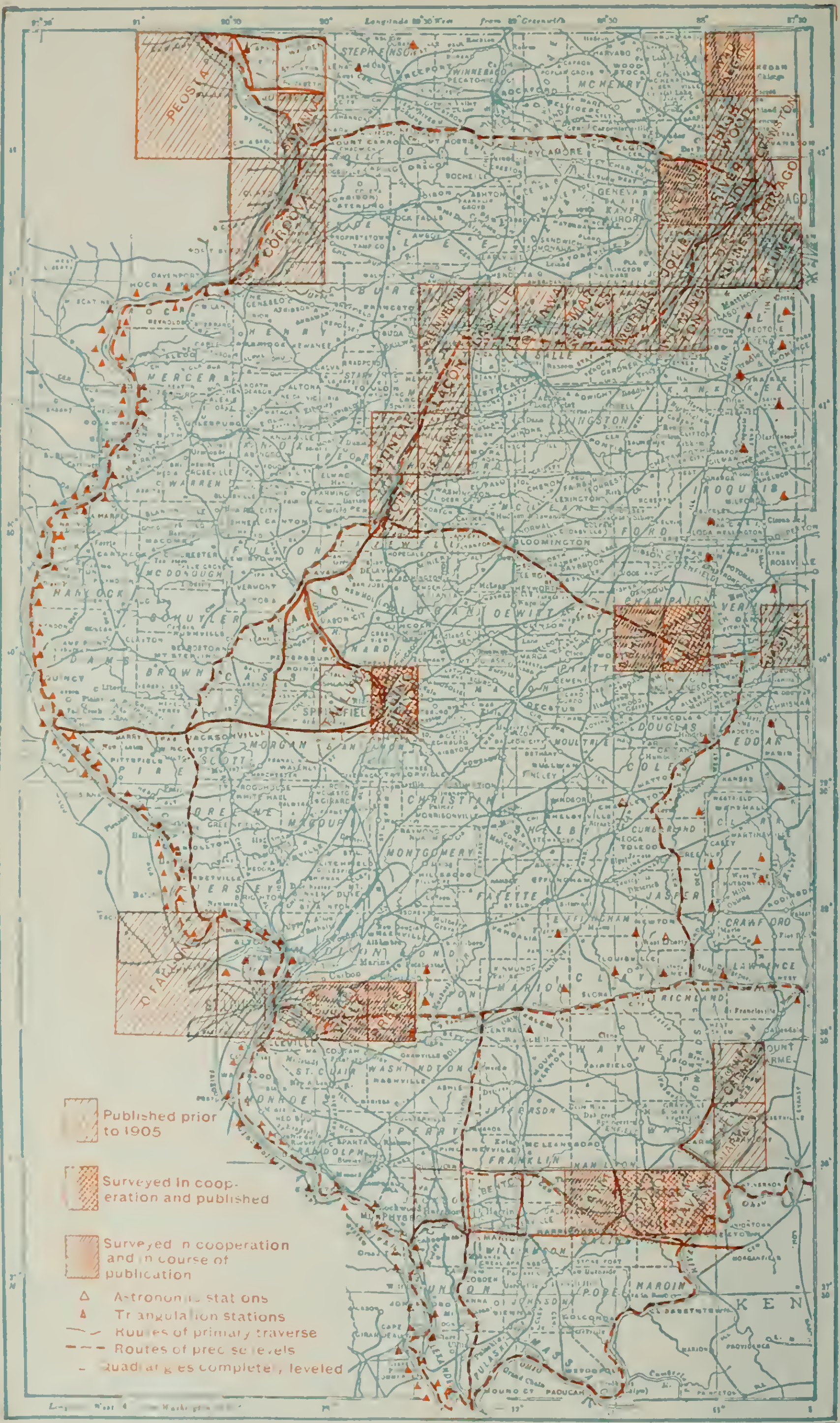
Some kind of a machine built on pretty much the same lines as the one used in the vibration tests described here this evening, but on a much larger scale; that would show the component of all those forces which I have outlined as applying to cars when rounding curves would be of great value. Some of our modern freight cars weigh when empty 46,000 lbs., or twenty-three (23) tons, and when loaded have a total weight of 156,000 lbs.; these are sometimes hauled at a speed of 40 to 50 miles per hour, and under certain track conditions they possess a rolling, or swaying motion; the effect of which, at the present time, we have no means of measuring; we know, as a fact, that it is something terrific in its effect both on the equipment and on the track. Sudden lateral thrusts break a car wheel flange; possibly it is a component of velocity together with weight of car and contents. At times this fracture may be assisted by the flange being somewhat worn, and imperfect roadway would also contribute to the same result. Some machine, that will accurately measure and record the motion of cars under these conditions, and at the same time indicate at what particular place on the line of road the readings were taken, so that an accurate description of the track at that point could be added, would be a great benefit. It would possibly indicate by its application to different kinds of cars (and at different speeds), for instance, refrigerator cars, loaded or empty, furniture cars, coal cars, box cars and others, that speed which might be considered a *safe* rate for one class of these cars, would be *absolutely dangerous* for others.

Following the wreck of a railway train, the different departments involved, as a rule, are called upon to explain why, particularly when the cause of the wreck may have been assigned to a defect, or a condition chargeable to any particular department. Generally each department, including the mechanical, transportation and maintenance of way, attempt to show, or explain, that the real difficulty rests with the other fellow, and is usually able to make rather a strong case from his own point of view; as there are usually many broken wheels, bent axles and bady damaged trucks in a wreck, it is difficult to reach a conclusion as to whether some of them *caused* the accident, or were the result of it, and if a series of tests could be conducted with some machine, as I have previously suggested, that would give some clear, comprehensive ideas of the behavior of cars of different types, and under the different conditions mentioned. When running and at the same time taking note of the track condition, or in some manner indicating the point where the readings were taken, it would furnish excellent means for not only checking up track conditions, but it would also indicate what classes of cars are best suited for certain speeds. I am quite sure the results would not only be very interesting, but useful, valuable and welcome information to the railway managements.

Mr. Huels—At the University we have a lot of students who have to write a thesis before they graduate, and I am sure, if the railway companies and men like Mr. Symons, who have these problems to work out, would give us a list of them, we might be able to put some of the students to work on them, and perhaps get some results that would be of value.

There is one point that comes up in connection with these two kinds of train lighting sets that seems to be of considerable interest. It was suggested to me by Mr. A. J. Farrelly, Electrical Engineer of the C. & N. W. Ry. It is the factor you might call the gyroscopic action of those lighting sets. Take a bicycle wheel and hold one end of the shaft in each hand; if the bicycle wheel is at rest you can change the plane of the wheel very readily; but if the wheel is set to spinning rapidly and if you now try to change the plane of the wheel, there is a resisting pressure on your hand. I do not know just what the resisting pressure is, but the greater the number of revolutions per minute, the greater is the resistance pressure on your hand. You can imagine that same thing taking place in a lighting set. Take a Westinghouse set, running at 400 revolutions per minute; there is a certain gyroscopic action there. Take the Curtis turbine, running at 3,600 revolutions; there is certainly a greater gyroscopic action there. The De Laval Steam Turbine Co. also puts out a lighting set, and in their small sizes the sets run at 10,000 to 30,000 revolutions per minute. There certainly must be a still greater gyroscopic action in a De Laval set. In addition to that the Westinghouse people have a shaft 5 or 6 inches in diameter—not smaller. The General Electric Co. has a shaft about that size, while in the De Laval turbine the shaft is as small aso 1 inch or less, and is made flexible on purpose. The way that factor comes in is in this way: take your equipment—say the De Laval—and set it lengthwise of the car; your train is going 40 miles an hour; suddenly it comes to a bend in the road, which turns the set around suddenly. The question is, is that bend great enough to spring that shaft so it will break? Another point is, is the effect of that gyroscopic action greater when the lighting set is placed lengthwise of the car, so that the shaft is parallel to the axis of the train, or greater when the lighting set is placed crosswise? You sometimes hear of a train lighting set coming in with a broken crank shaft, and I have heard of a Curtis turbine falling to pieces and damaging the cab. You might look for some danger to the bearings breaking, due to this gyroscopic action. That is a question we do not know anything about. The people who put out those engines say, "Well, we have sets that are running all right." But it is a problem that it would be well to look into.

Mr. F. C. Harper—Mr. Symons mentions the fact of flange breakage. I know of a case on construction track, where there was an excess of flange breaking. The track was in poor condition, as is usual on such work, and the tonnage extremely heavy. The flange breaking caused a number of wrecks and was such a serious detriment in the operation of work trains, causing directly and indirectly an item of expense so entirely out of proportion, that the railroad company sent an expert down to look at the wheel flanges, examining them rather than the track which caused the trouble. It occurs to me that possibly if they had examined the track more closely they would have been able to quickly locate the cause of the trouble. It would have been economy in the construction of the track to have spent more money for ballast, etc., enabling a better track to have been equipped, and incidentally at a less expense for maintenance and broken wheel flanges.



Map showing progress of coöperative topographic surveys.

THE WORK OF THE STATE GEOLOGICAL SURVEY.

By H. Foster Bain, Director.

Presented February 6, 1907.

About two years ago Mr. A. Bement read a paper before this society urging the need of a State Geological Survey. The paper attracted much attention, and the interest aroused by it was a large factor in bringing about the passage of a bill providing for such an organization. The Forty-fourth General Assembly made an appropriation of $25,000 per year for the first two years for beginning the work. Bills are before the present General Assembly to provide for its continuation and expansion. As many of you were interested in getting the Survey started I am glad of an opportunity to tell you briefly of what we have attempted to do, of what we have done, and something of our plans and hopes for the future.

The older notion of a geological survey was that such an organization should be highly scientific and only incidentally economical in character. We are hoping that our own work, while not one bit less scientific, may be as direct and practical in its results as is possible to make it. Formerly geological surveys were concerned with the study of mineral resources from the point-of-view mainly of mode of occurrence and distribution. To this we are adding the study of their utilization. It is felt that at least certain aspects of the preparation of materials for the market and their actual marketing, are of sufficient general interest to warrant their inclusion among our studies. It is important to know thoroughly the stratigraphy of our Coal Measures, to know intimately the occurrence and distribution of the various coal beds, and the composition and character of the coals; but we want also to know the facts relating to its occurrence in the ground, the character of roof and floor, of gas and water, which must enter into the problems of mining the coal, both from the point-of-view of safety and cost. We need thorough studies of waste in coal mining, both avoidable and unavoidable. We need also data relating to the use of coal, its efficiency under boilers and in the producer or gas retort, its freedom from smoke, and the adaptability of the different market grades to particular uses or trades. Similar studies are necessary as relates to clay, stone, cement materials, glass sands, and all the other mineral resources of the State, and the Geological Survey, either alone or in co-operation with other organizations, should, I think, do what it can to meet this demand for information. We have accordingly interpreted our function broadly, and where we have failed to enter a field it has been through lack of men and money rather than through lack of will to do. Practically we have so far found it impossible to take up more than a small portion of the work outlined.

The Geological Commission was organized in August, 1905, by the appointment of Professor T. C. Chamberlin of Chicago, thus completing the board; the other and ex-officio members being Governor C. S. Deneen, and President E. J. James of the State University. The present Director was selected in September, but owing to other engagements was unable to assume the duties of the office, even in part, until November. Accordingly we have so far had only one field season. This accounts in part for any apparent meagreness of results.

TOPOGRAPHIC SURVEYS.

In the organization of the Survey two major lines of work have been recognized, Topographic and Geologic. As was contemplated by the act establishing the Survey, the topographic work has been carried on in co-operation with the U. S. Geological Survey, under the general supervision of Mr. H. M. Wilson, Geographer of the U. S. Geological Survey, in charge of the Eastern Division of Topograph and under the immediate direction of Mr. C. E. Cooke in 1905; and in 1906 under W. F. Herron, Topographer in charge of the Central Section. The members of this society are already familiar with the character of these maps. The accompanying map and table exhibit better than words just what areas have been covered.

During the field season of 1905 and 1906 there were mapped 2,492 square miles, at a total expenditure for field and office work of $39,735, of which one-half only was paid by the State. Including the cost of primary triangulation and precise levels and uncompleted mapping, this is at the rate of nearly $16.00 per square mile. This control includes a large amount of preliminary work toward future topographic surveying, there remaining about 1,200 square miles controlled by primary triangulation and precise leveling through which to reduce future spirit leveling to mean sea level.

Topographic surveying will have been completed on 11 sheets during the two years of co-operation. The following tabular statement gives the names of these sheets, their area within the State, scale, contour interval and year mapped:

TOPOGRAPHIC ATLAS SHEETS MAPPED BY THE STATE AND THE UNITED STATES GEOLOGICAL SURVEYS IN CO-OPERATION.

Quadrangle	Area Mapped	Year of Survey	Contour Interval	Scale
Belleville	223.28	1905	20	1:62500
Breese	233.28	1906	20	1:62500
Eldorado	235.66	1905	20	1:62500
Galatia	235.66	1906	20	1:62500
Mahomet	228.40	1905	20	1:62500
New Haven (Ill.-Ind., Ky.)	192.78	1905	20	1:62500
Springfield	229.22	1905	10	1:62500
Urbana	228.40	1905	10	1:62500
Waukegan (Ill.-Wis.)	149.00	1906	10	1:62500
Wheaton	225.50	1906	10	1:62500
In process of mapping:				
Tallula	211.00			
Total	2402.18*			

* In addition 90 square miles were mapped over the edges of quadrangles in 1906.

GEOLOGIC WORK.

At the beginning it was decided that the geologic work should be temporarily concentrated upon a study of the coals and clays of the State, these being its most important mineral resources. Provision was made for a small amount of work in connection with water, oil, lead and zinc, and general stratigraphy with a view to later expansion. It was not found practicable with funds available to make any investigation of the cement materials or any other than a most general study of the quarry products and miscellaneous non-metallic minerals. Additional funds are urgently needed for this work.

Coal. The study of the coal and coal fields of the State has been carried on both in the field and office. A considerable portion of the funds of the Survey have been devoted to stratigraphic studies of the coal measures, since a thorough knowledge of the stratigraphy of the field is essential to its economical development. Money so spent advances the study of the associated clays, limestones, cement materials, water and other minerals as well as coal.

In informal co-operation with the Federal Survey detailed studies have been made of the areas adjacent to Peoria, Springfield, East St. Louis and Eldorado. It is proposed to continue and extend this work, particularly in the southern part of the state, so as to cover first the regions of active mining. Arrangements have been made for beginning the revision of the topographic base in the LaSalle coal field next season. This is to be followed by a careful stratigraphic study.

Investigations of the composition and uses of coal have been taken up in co-operation with the Department of Applied Chemistry and the Engineering Experiment Station of the University. The chemical work has been done under the direction of Professor Parr and has been directed to a study of both the ultimate and proximate composition of coals.

A whole new set of samples have been cut in the mine from a clean face of coal, taking the entire workable thickness of the bed and marking on an accompanying section all partings included as well as rejected in sampling. The samples were promptly quartered down and shipped in an air-tight galvanized iron can so as to arrive in the laboratory without loss or gain in the natural moisture, and are now being analyzed. Whatever additional sampling may prove later to be necessary, it was thought that the first step must be the careful determination of the composition of the coal as it is in the ground.

Preliminary studies on the effect of weathering on the fuel values of coal have been also taken up. In connection with the Engineering Experiment Station a study of washed coals has been begun. It is felt that better preparation of coal for the market is a matter of supreme importance, particularly to the extent that it may reduce the amount of smoke made in burning. The Engineering Experiment Station has underway a series of boiler tests on the same coal washed and unwashed, and the Survey is co-operating with the station in this work.

To a very important degree, the mode of occurrence of the coal determines the methods of mining and the cost of the work. Thorough studies along these lines are highly desirable. A beginning has been made in connection with the work of sampling the veins and the stratigraphical work already discussed. At Peoria detailed studies have been made of the puzzling series of faults which have interfered seriously in places with mining. At Springfield the "horsebacks" have been investigated, and at other points in the State similar phenomena have been under view. A much more thorough and complete investigation should be undertaken, and undoubtedly would be productive of results of value. One phase of the subject of pressing importance is the occurrence of gases in mines and their influence in causing and extending explosions. The loss of life and property as a result of explosions in the coal mines is a constant and serious burden. In the six years ending June 30, 1906, 869 lives were lost in our mines. Of these 226 were due to explosions of one sort or another. There should be a thorough and comprehensive investigation of the entire subject to the end that proper precautions may be adopted to prevent or minimize this loss. As a larger number of deep mines is opened in the state it is to be expected that more gas will be encountered, and preparations should be made to meet these conditions. A certain amount of waste is inevitable in all mining, but effort should be directed toward reducing it as much as possible. A first step toward this would be a careful study of the present waste and its causes. It has been recently stated that the per cent of waste in coal mining in Illinois is greater than in any other state. Whether this be true or not it is impossible to say, but all will agree that whatever the amount, it is too much and should be reduced. This is an important subject which demands thorough investigation.

The study of the marketing of our coals is less directly a part of the Survey work, but it is one of great importance and may be made of the greatest value to the State. For some years the capacity of our mines has been ahead of the demand, and with the increasing demand for smokeless fuel eastern coals have cut into the markets naturally belonging to Illinois. Much good can be done by disseminating correct information regarding methods of burning so as to produce the minimum of smoke. Probably also good results would follow a careful study of the particular demands of our natural markets as regards size of coal.

Clay. The investigations of the clays have been carried on in connection with the Department of Ceramics of the State University. The principal work of the year has been a study of paving brick clays. This has involved visits to all the paving brick plants of the State, with a study of their processes and the thorough testing of samples of their products. In addition barrel samples of the clay have been shipped to the laboratory, prepared and burned under known conditions and results noted. For purposes of comparison similar samples of clay and brick from the leading plants in Ohio, Indiana, Missouri, and Kansas have been collected and also tested. The results of the various tests are now being tabulated, and a report on the subject will be ready for printing shortly. The investigations show not only that we have large resources of excellent material in Illinois, but also throw important light upon the technology of paving brick making.

A second line of investigation taken up within the year was a preliminary study of the fire clays of the State. In all forty-six clays were examined, and of these thirty-nine stood a fire test equivalent to 1670 degrees centigrade or higher, and may accordingly be considered refractory. Many of the remaining may be used in situations where a lower heat in sufficient.

Much more work is needed on the fire clays, and in addition the pottery clays, tile clays, terra cotta clays and various building clays demand investigation. Second only to coal, our clay working industries are the most important ones founded on our mineral resources.

Oil and Gas. Important deposits of petroleum were discovered in southeastern Illinois late in 1904. Shipments began in June, 1905, and by August, 1906, the output had grown to 800,000 barrels for the month. This development has been exceedingly gratifying. Promptly after the organization of the geological branch of the survey, steps were taken to make a proper study of this important new mineral resource. In April and May the entire field as then developed was studied for us by Professor W. S. Blatchley of Indianapolis, State Geologist of Indiana, and an experienced oil expert. Professor Blatchley's conclusions were most encouraging, and his report, forming Bulletin 2 of the present series, was promptly sent to the printers

The oil field has continued to develop rapidly, and additional surveys will soon be necessary. Large volumes of gas, estimated at 50,000,000 cubic feet per day, are now being found.

Educational Bulletins. Following the example of some of the other Geological Surveys, we have planned the publication of a series of educational bulletins. Their purpose is to put into available form such knowledge as will help those who are not geologists in understanding the common phenomena of their own regions. Five bulletins have been undertaken. One of them has been completed. The field work for three others has been essentially completed, while the work for the fifth is under way.

Other work. Minor investigations of lead, zinc, fluorspar, silica quarry products and other materials have been undertaken, but in general, funds have been lacking for any adequate study along these lines. This is particularly to be regretted in the case of cement materials. Since 1902 the cement industry of the State has been nearly stationary. In the meantime nine new plants have gone into operation in neighboring states, and a number of others are now building. The percentage of the output of the United States, made from materials abundant in Illinois, has jumped from 21.4 to 35.9, and the increased demand for cement has been enormous. Enough is known to indicate that there is an abundance of cement making materials, particularly in the southern part of the State. The large fuel supplies available, the good transportation facilities enjoyed, and the fortunate geographic situation of Illinois, entitle it to a greater share in the increased cement production.

Publications. Three bulletins and one statistical circular have been printed and distributed. Manuscripts for four additional bulletins are now in hand and being prepared for the printer. In addition a number of reports are in a more or less advanced state of preparation.

Information bureau. One very important portion of the State Survey work is the answering of inquiries regarding the mineral resources of the State. These inquiries come from all classes and from all parts of the State as well as United States. Land owners, manufacturers, miners, mine operators, oil prospectors, lawyers, teachers, railway industrial agents and many others have availed themselves of the services of the Survey in the last year.

Water resources. Adequate supplies of pure water for municipal and industrial purposes are becoming harder to obtain year by year. As the population becomes denser this difficulty is likely to increase. Since the distribution and occurrence of water is a geological problem, the Survey has taken up studies designed to throw light upon the sources of water supply. In this work it has co-operated with the State Water Survey, the Engineering Experiment Station, and the U. S. Geological Survey, in certain general studies.

The detailed study of the water resources of the East St. Louis District was also undertaken in June. The report has been finished and illustrations are now being prepared. Many points of interest to the water users were found, and it is believed that conclusions will prove of large value to the people of the district concerned.

Another line of investigation, which it has been suggested the Geological Survey should take up, relates to the swamp and overflowed lands, the action of rivers, and the method of drainage. Large areas of land have already been reclaimed by drainage, and many local drainage districts are now in existence. When, however, the problem of the control of a whole river such as the Sangamon, Kaskaskia, Embarass or Little Wabash is approached, it is at once found that the data are not now available upon which to plan a comprehensive and economical system. Numerous stream gaugings are needed, the area of the water shed, the rainfall and the course of the main river and its tributaries must be studied if the best system of river control is to be adopted. The topographic maps now being made by the Survey will afford much of the data, but other material can only be obtained as a result of special study. Land is becoming exceedingly valuable in Illinois, and a wise provision for the future would suggest the reclaiming of every available acre. In order to prevent waste and misdirection in expenditure a certain amount of preliminary study sould be devoted to the problem, and at the same time the surveys of the river valleys should be advanced as rapidly as possible. While there have been numerous demands for the Survey to take up this work, the Director and the Commissioners have not felt free to do so, with the resulting diversions of funds from other lines of investigation. It is accordingly proposed to ask the present General Assembly for a special appropriation so as to enable a field party to be organized for this particular work. The special surveys of the river bottoms can then be pushed in advance of the regular topographic survey, at the same time that stream gauging and stream study may be taken up. Out of this work data will come for the planning of a wise and economical scheme of reclamation.

Plans. For the next two years the work of the Survey, if legislative approval be secured, will consist of a gradual expansion of the present scheme of topographic mapping and stratigraphic studies. It is proposed to continue the special investigation of coal and clay, to inaugurate similar studies of cement materials, and of quarry products, and to make special studies of coal mining conditions as related to explosions and waste in mining. Finally it is hoped that a beginning may be made in the survey of the swamp and overflow lands and the study of the means necessary to control our inland rivers.

CO-OPERATIVE TOPOGRAPHIC SURVEY OF ILLINOIS.

Wm. H. Herron, of U. S. Geological Survey.

To produce an accurate, and satisfactory map of any extended area, such as a state, its relative location upon the earth's surface must first be fixed. To do this the geographic positions of a large number of points must be determined.

The three methods employed are by astronomical observation, by extending triangulation from points whose positions have been previously determined, and by primary traverse, which consists in determining new positions (from old ones previously established) by a series of linear measurements combined with angles, similar to the method of running a preliminary railroad line with a transit.

These three operations, together with the careful determination of a system of elevations, are included in the term "primary control."

In inaugurating the co-operative topographic survey of Illinois in 1905 the utilization of all available data for primary control was carefully considered.

The triangulation of the U. S. Lake Survey, extending from the Wisconsin state line southward along the eastern side of the state as far as Crawford County was available for controlling that portion of the state's territory. The southern terminus of this triangulation intercepted the trans-continental triangulation of the

U. S. Coast and Geodetic Survey, the trans-continental work extending westward from Crawford County to St. Louis, furnishing excellent control in the southern part of the state.

The triangulation of the Mississippi River Commission extending from Cairo to Dubuque controls the western boundary of the state for the entire length, and the U. S. Engineers' survey of the Illinois river extending from the vicinity of Alton to Chicago, gives a second connection of the Mississppi river data with that of the U. S. Lake Survey.

The precise level lines along the Mississippi river for the entire west boundry of Illinois; along the Illinois river from its mouth to Joliet and across to Chicago; along the Ohio river from its mouth to the Indiana state line; from East St. Louis to Vincennes, Indiana; from Cairo to Sandoval; and from Chicago westward to Savanna along the Chicago, Milwaukee and St. Paul R. R. furnishes a well distributed basis for the expansion of our system of levels for the determination of elevations.

The utilization of this data, all of which is of most excellent quality, means an enormous saving of funds in completing a topographic map of the state. During the two years' progress of the work we have run additional precise level lines in such manner as to further divide the state into districts. In conformity with the practice of the federal survey the entire area of the state has been divided into quadrangles by parallels of latitude and meridians of longitude; this division has great advantages in the way of uniformity in size of, and ease of reference to the different sheets. The approximate area of each quadrangle is about 220 square miles.

The first field work consists naturally of extending the primary control from points already established to the area selected for mapping.

The method principally employed in Illinois for the past two seasons for horizontal control has been that of primary traverse around the borders of each quadrangle in the proposed area for survey, which has been started from a previously determined position, (usually a triangulation station of one of the various belts of triangles heretofore enumerated), lines being run in closed circuits. Additional horizontal control is furnished on many sheets from triangulation points located within the area.

The primary traverse consists of alignment accomplished by series of angles measured with engineer's transit and distances obtained with a three-hundred foot steel tape which is used with a uniform tension of 20 pounds, by means of a spring balance at the front end of the tape. The alignment is checked by observations on Polaris at the end of each day's work when practicable, and azimuth stations are not more than ten miles apart except on long tangents.

Permanent marks, either standard bronze tablets or iron posts, are placed at each corner of a quadrangle with an intermediate one on each of the four sides.

The positions of practically all section corners, important road junctions, and important points along the route of the primary traverse line are computed and furnished the topographer for use on his field sheet as a base for development of the detailed planetable work.

The vertical primary control is secured by means of a primary level line run in circuit around and across the quadrangle starting from some previously established datum. This initial datum is usually a point on one of the many lines of precise levels heretofore described.

The instrument most in use for primary level lines is a 20 inch wye level. The maximum error (in feet) allowable on such lines is, 0.05 times the square root of the distance in miles. Permanent metal bench marks are left not farther than three miles apart along the lines of levels, and the routes are so planned that at least one bench mark shall be placed in each township or equivalent area.

The primary parties are followed by traversemen and secondary levelmen. The traverseman with a 15 inch planetable, compass, and sight alidade, surveys each highway and railroad on the area, obtaining distances with wheel, tape, or stadia. He locates stream crossings, railroad crossings, houses, and section corners and sketches timber areas, along his routes of traverse and ties his lines to points of the primary control. He makes no attempt to adjust his work on this sheet but indicates clearly each error of closure. All towns of two thousands inhabitants or more are surveyed on double the field scale.

The secondary levelman, equipped usually with a 15 inch level starting from some point on the primary level line, extends the lines of elevations over practically all roads within the area to be mapped. These lines are arranged in circuits and are either closed upon themselves or on other points of the primary lines. Elevations are painted up at all road crossings and junctions and at frequent intervals along his routes. His circuits are comparatively short, and his bench marks are temporary in character, the object of his work being to supply information to the topographer who is to follow him immediately. He works therefore much more rapidly than the primary levelman and the standard of accuracy not being so high the cost is comparatively reduced.

The final field work for the topographic maps is accomplished by the expert topographer, who is provided with a planetable and telescopic alidade.

Before taking up the actual work of the field he has constructed upon his field sheet a polyconic projection of the area, to which has been referred all points of primary control. The work of the traverse man is then adjusted and transferred to this previously controlled sheet.

This data in addition to the elevations established by the level parties furnishes him an accurate basis for the development of such additional information as is necessary for the sketching in of the contour lines. The sketching of relief is one of the most important features of the field work and is assigned to men of experience and skill.

The sheets already published or in process of publication in Illinois since cooperative work began are:

In Southern portion of State	In central portion of State	In northern portion of State
New Haven	Springfield	Wheaton
Eldorado	Tallula	Waukegan
Galatia	Mahomet	
Belleville	Urbana	
Breese		

New Haven, Eldorado, and Galatia sheets are controlled horizontally by a primary traverse line starting from the U. S. Coast and Geodetic triangulation point near the state line in Knox county, Indiana, and checked upon the astronomic position at Henderson, Kentucky; and vertically by lines of primary levels surrounding each sheet started from a point on the trans-continental precise level line.

The Belleville and Breese sheets, horizontally by primary traverse line starting and closing on triangulation points of the U. S. Coast and Geodetic Survey, and vertically by primary level line starting and closing on the trans-continental precise level line.

The Springfield and Tallula sheets, horizontally by primary traverse line starting from a triangulation position of the Mississippi River Commission on the Mississippi river and closing on the triangulation position of the U. S. Engineers' Survey of the Illinois river; and vertically, by a primary level line starting and checking on points of the U. S. Engineers' survey of the Illinois river.

Mahomet and Urbana sheets, horizontally by primary traverse line starting and closing on triangulation points of U. S. Lake survey; and vertically, by primary level lines carried from Pekin, Illinois, from the U. S. Engineers' survey of the Illinois river.

Wheaton and Waukegan sheets, horizontally by primary traverse lines developed from and checked upon U. S. Lake survey triangulation points; and vertically, by primary level lines starting from points on U. S. Engineers' precise line from Chicago to Savanna.

DISCUSSION.

President Abbott—I should like to discuss Dr. Bain's paper from a learned standpoint if I were able; fortunately we have with us a number who are able. Some of these I will call upon, and and then I hope we may have general discussion.

Dr. U. S. Grant—I take it as a matter of irony that I should be called upon to discuss the matter *learnedly*. It occurred to me, when Dr. Bain was talking, and when he said he was not going to give any reasons for his existence, that he has given the very best reasons for his existence that could be given. I think Dr. Bain must be somewhat of a politician, for we all know that he associates a good deal with politicians in Springfield.

There are some interesting features in the map which shows the red question marks. It occurred to me that Dr. Bain would have done well if he had put on the map by means of some lines other than red, the localities where he answered questions satisfactorily. I also think he might have shown on that map by some golden lines the localities where his answers brought fees to the members of this Society. I notice that the northeast corner of the map has a large collection of question marks, and that leads me to think that the people in the locality of Chicago are great seekers after the truth.

Dr. Bain has spoken of some work having been done by the State Survey in lead and zinc. Last summer in the northwest corner of the state a little work was done in the heart of the lead and zinc district, in the way of producing a detailed map of a small area. This map is of small size, but on a scale of 4 in. to the mile, showing 10 ft. contour intervals, and gives accurate levels in many places. Drawn from these levels and other data are contour lines on the base of the Galena limestone, which marks the depth to which the mining will usually be carried. We were able to show, by means of these contour lines, the form of the surface of the base of this limestone, and to show also the actual depth at any particular point to the bottom of the ore horizon. We were able in Wisconsin to be of considerable service in this same line, and many drills and shafts have been sunk since the maps were made, and in many cases the depths to the bottom of the ore-bearing formation have been found to check up within three or four feet of what was predicted on the maps.

Another point is that the ore deposits there are laid largely in synclinal basins, and the existence of those basins are so closely shown by the contours as to enable one to tell the favorable places for prospecting.

The talk which Dr. Bain gave brought to my mind another idea, and that is the change which has taken place in the attitude of geological surveys towards economic work in the last 20 or 25 years, and I might also say the change that has taken place in the attitude of the geologist toward the mining man. Some few years ago the mining man looked upon the geologist as a mild sort of lunatic, and the geologist looked upon the mining man in an almost equally uncomplimentary way; but present developments have shown that the geologist and mining man are getting close together. It seems to me that this State Survey work will be of great assistance to both classes of individuals, and that the work is not only of economic character, but also of the very highest scientific grade. I think we are to congratulate ourselves and the State that this kind of work is being done by our Survey.

Mr. W. W. Atwood—What I have to say is hardly in the nature of a discussion, so I have not the right to take up much time.

I notice that Dr. Bain has said nothing about one of the maps exhibited. I refer to the geological map that shows the general distributions of the formations which underlie the State. Such a map will be very valuable to engineers and geologists.

I was specially interested in hearing his reports of dikes in the southern part of the State. From the scientific standpoint these finds are of peculiar interest.

One line of work which Dr. Bain would speak of as secondary and one of the minor lines as far as the Survey is concerned, is the preparation and the publication of a series of educational bulletins. This Survey has appreciated the fact that a great deal of scientific work has its greatest value as an educational force. I know that the Commission, with Dr. Bain, are working out a series of Bulletins, which will be immediately valuable in certain regions, and in a general way valuable to every citizen of the State. There are a number of men at work and these Bulletins will be published as fast as it is possible to get them ready. I know he has had men at work in the East St. Louis region, one along the Mississippi and another along the Illinois. Such Bulletins, I believe, are going to help the Survey to continue to get its appropriation, for they will be appreciated by many people who would not otherwise receive any benefit from the Survey.

The Wisconsin Survey has published a similar series of educational papers which have been very satisfactory. Of course they would not be immediately interesting to members of this Society in their regular work as engineers, but to those engaged in instructing the young people of the State, this is a valuable contribution. I would ask if there are not some points in connection with the geological map that Dr. Bain did not bring out and which he would like to bring out now?

Mr. Geo. S. Rice (M.W.S.E.)—Referring to the map—like any first production of this sort, I think it has been put up to throw things at. I myself, have had occasion to make a few comments and offer a few corrections in detail. The map is certainly of very great interest, and I presume Dr. Bain will speak of it later.

Dr. Grant has referred to the Survey having found igneous matter in the coal in the southern part of the State. This suggests that there may be a mass of geologically-recent igneous matter concealed below the coal formation in certain localities in that part of the State. It will be interesting to know what influence this has had in the neighboring coal field beyond the immediate vicinity of the dike. I think it is generally accepted that a movement, such as the Ozark uplift, has the effect of kneading the coal, and often, as in the far west, if the coal contains a good deal of moisture, it has the effect of lessening the percentage of moisture in the coal, increasing the fixed carbon, etc.

Returning to the mining features, I think that it will be a valuable thing if the Survey can bring to the minds of all of us—more particularly, perhaps, the owners of coal land, as well as the public in general—the tremendous losses now going on in connection with the mining of coal. I think Dr. Bain is correct in saying that there is probably more waste in Illinois than most any other State, partly owing to the roof of a vein, which requires very large pillars, and also to the softness of the bottom. In mining, if there are not sufficient pillars left, the strong roof pushes the coal down into the bottom, causing much expense. The first thought that comes to the mining man is that he will simply increase the size of his pillars, and we have a condition in many mines where 50 per cent. of the coal is in pillars. They do not take those pillars out, and when the mine is abandoned the rooms are shut up, the tracks withdrawn, etc., and it would be expensive to open up the workings again. Under the State law the mining companies file with the State Inspectors the maps of the mines, but as far as my knowledge goes the State Inspectors are not given facilities for keeping these records, and so, if you go to any Mine Inspector and request permission to see certain maps, the result is generally that they cannot be found.

As the mining interests become greater, and more and more mines are worked out and abandoned, it is important that those records should be preserved, not only for safety of life, but from economic conditions, because if you do not know what are the limits of the old workings, you are bound to leave excessive barrier pillars.

I think it is easy to see one's way clear to improve the mining conditions under the present system. The trouble is, coal is too cheap from the standpoint of the operator, so he is not given much leeway. It is usually cheaper to leave large pillars for the roof than to remove them. Most mining men who are conversant with mining systems know that the coal can be gotten out if required. It is largely a system of blocking out the ground, driving steel entries, putting in rooms, withdrawing the pillars as fast as the rooms are up, and allowing the work to cave behind within each block. Of course each case needs special study—the depth from the surface, the character of the coal itself, character of roof, floor, etc., all enter into the calculations. I think it will be a splendid thing if the Survey can give us some data on which to work along these lines, obtain figures for the strength of sample roof material, treating the roof as a beam. In regard to the bottom or floor, that should be studied to see what pressure would cause the material to "flow" as the pillar may be pushed down into it, also to find the crushing strength of the coal.

President Abbott—I think Mr. Rice has explained why there is such great waste of coal in Illinois mining. If the mine owner can buy coal in the ground at a cost of less than ½c per ton and if it would cost him 5c per ton, or more, to remove the pillars, (possibly it would cost a good deal more than that), it shows at once that it would be more advantageous to the operator to carve into nature's store-house, grab what he can most easily, and, like a vandal, destroy the rest so no one else can get it, rather than to devote one or two extra years at a great first cost to drive the entries to the extreme end of his property, and begin there to mine backwards, pulling the pillars behind him. Moreover, such a method of mining would let down the roof and break up the surface, which he does not own as a rule, and it is worth several times as much as he has paid for the coal. It has always seemed to me a pity that posterity could not step in and legislate against the destruction of these great deposits of coal which have been laid up for their use, and so much of which are being wasted by operators.

Mr. Bement (M.W.S.E.) :—I do not propose to offer an extensive discussion to Dr. Bain's paper, but rather to make a few suggestions.

The matter of coal analysis or determination of coal values is one of rapidly increasing importance. Nearly every geological survey has done some work along this line. In the past, however, it has not been sufficiently comprehensive to be of much worth. The disposition has been rather to devise some plan of fuel ratios as the most important feature; for example, such as the Second Pennsylvania Survey—schemes which have little or no useful application. Requirements, however, are becoming more exact and there is an absolute necessity and demand for comprehensive and accurate moisture, ash and heating power values, because it is rapidly becoming the practice to buy and sell coal under specifications very much as with steel; the information thus far publicly available is of little or no value and at the best only confusing. The reason for this is, that analytical work has not been based on proper sampling, although the matter of securing correct heating power is one which has not been satisfactorily worked out. Improvement may be made in reporting coal analysis so that it will be more readily useful and understood, by stating ash values on dry basis and heating power on the pure coal basis; thus values are readily comparable and calculations more easily made. These individual statements should accompany the combination of values in the usual moist coal composition, in which form chemists usually present results.

The reporting of the factitious values known as "air-dried" moisture should be abandoned. This is a suggestion which I repeat at this time, and shall do so as long as chemists continue to employ this feature.

The amount of chemical work which the survey should do will have to be settled by the people of the state, because it will cost a considerable amount of money to do it right and this fact must be realized. The importance of having correct data regarding fuel values is very great, and as an illustration in this connection I have made some figures. Assuming that the coal production of Illinois is 38,000,000 tons per annum; at a value of $2.00 per ton it would make a total of $76,000,000, of which amount on a mine run basis under present conditions, there is $11,400,000 paid for ash which the operator is compelled to sell and the consumer to buy. It is, of course, impossible to entirely eliminate ash from coal, but the present approximate average of 15 per cent. in mine run coal is too high. It is entirely probable that it should not average above 10 per cent., therefore the excess of ash of 15 over 10 per cent. equals for its weight alone at $2.00 per ton, a sum of $3,800,000 pr annum. This, however, does not represent the full damage, as on page 557 of Vol. II, *Journal Western Society of Engineers,* there is a curve showing efficiency obtained in steam generation with coal containing varying percentages of ash, from which it would appear that in addition to loss due to the actual weight of the ash, its presence interferes with the combustion a sufficient amount to increase the loss to $4,016,600, and if the Geological Survey could point out a way to save one-fourth of this, it would justify the expenditure of a very much larger sum than Dr. Bain will probably ever feel like asking for. The cause of this ash in the coal is due to the carelessness and recklessness of miners, as well as their failure to clean the coal.

There are three great evils in coal production; one is the great quantity of ash regarding which I have already spoken; another is the excessive quantity of fine stuff produced by reckless blasting, with its attendant dangers, and the other is the enormous loss in coal due to bad mining methods and practice of leaving pillars. This latter is something to which Dr. Bain has referred and is a matter which does not actually concern us at the present time, but if the people of the state are going to leave a larg debt for future generations to pay off, it should also conserve out assets for their use, yet it is no doubt a fact that the coal left in the ground in Illinois is much greater than in any other state in the country.

In reference to the suggestion that a study of coal be made from the standpoint of smoke, I do not think I disagree with Dr. Bain, although I would emphasize the mater from a somewhat different standpoint. All of our coal smokes, and it would be difficult to draw a line between that which is more smoky or less so, therefore the requirement is not for a smokeless coal bcause there is no such thing so far as the bituminous variety is concerned, but rather for an apparatus which will burn any kind of coal without smoke, and in this connection the Geological Survey and the Experiment Station can do a very good work for the people by laying before them results of investigations and studies which have been made, showing that it is not only possible but economical to burn coal without smoke, and to also illustrate certain types of apparatus which accomplish this result, so that the people may be educated to understand the matter more fully.

Mr. J. H. Warder—I would like to ask about the dikes; is there any surface indication of their presence, or were they found only after working the mine? Also, what is the depth of the soil or earth above the mine roof? That has a tendency to crush down the pillars of coal left to support that roof. How deep are those mines from the surface?

Mr. Rice—As far as the depth is concerned it usually would mean from 200 feet and upwards, but even then if there is a strong limestone roof some 10 to 20 feet thick (it often runs that) if it has above it 125 feet, it might still cause, in the presence of water or moisture, the coal to be pushed down into the clay. A great deal depends upon the conditions—whether free from water or not. In shallow earth, every time there is a break in the roof, even if the break does occur in the roof there is enough shale above it to conceal the opening. In the case of long-wall mines, there all the coal is taken out as the work advances, there they are able to work underneath the Illinois river wtihout any difficulty, and I think, with a minimum roof of about 225 feet of rock covered with silt and clay above it; but the real tightness of the roof there would be furnished by the shale which, in the presence of water, would tend to puddle.

Dr. Bain (Closure)—The map referred to by Mr. Atwood and others seems to excite universal question, not to say derision. That is to show you the kind of map we do not want to make.

When we began our work we thought it would be good practice, to make a summary of what we knew and what we did not know. This map was based on an earlier one prepared by Professor Worthen and his associates. While I have no positive knowledge on the subject, I judge from his map that it was made in the office after the field work was done, and on the basis of notes accumulated in the field; we infer that there was no field map. You will notice in the new map certain areas in which the boundaries are put in with considerable detail. The differences in the map simply represent differences in the amount of information now available. The column or sections at the side illustrate the formations one would go through in drilling. We have a new edition of the map now in print.

With regard to the dikes that the secretary asked about. In about 1889 one dike was found across the river in Kentucky. In 1902 the United States Geological Survey people found one dike on the north shore of the Ohio river, and the following year six or seven dikes were found. These appear at the surface and can be seen along the river. These dikes found this year are at a depth of 400 feet and do not show at the surface.

In the matter of waste in the mines, that we realize is a very large problem. We are simply hopeful that by getting together the data available we may throw some light on the quesion.

The question of floor and roof is a critical point. The crushing is due to failure of foundation. The pillars of coal do not crush very much. I was particularly surprised recently to find that Illinois coal placed on a bed has a crushing strength of 2,000 pounds per square inch; so that the failure is due to the weight forcing out the floor from underneath; also to the breaking of the roof from above. As Mr. Rice suggests, we will have to get at the character of the roof and study it as a beam across an unsupported area.

I regret that more of you did not take part in the discussion. We would like to have your criticisms. We want to make our work as useful as we can, and we want to have some help in the way of suggestions or criticisms on what we are doing.

You might be interested in knowing about appropriations. The Legislature appropriated $25,000 a year to start this work; of that amount $10,000 goes into topographic work, $10,000 into geologic work, leaving $5,000 for work in general. This year we are asking for $50,000 instead of $25,000. Gov. Deneen feels that we can spend that amount of money to advantage, and that we need the money to carry out the lines of work which we have already taken up.

President Abbott—I am sure we have all been very much interested in hearing about this work of the State Geological Survey. Two years ago this society became interested in the work, and expressed to the State Legislature the desirability of having a State Geological Survey. With that precedence I do not think it would be at all objectionable if we should again express to the State Legislature our interest in this work.

[A resolution to this effect was introduced and passed by the Society, as recorded in the minutes of the meeting.—Ed].

The original paper by Dr. Bain was not read *in extenso* by him Feb. 6, but the substance was presented in an informal talk to those present. Sundry charts were exhibited which served to illustrate the remarks of Dr. Bain, and are referred to in parts of the Discussion. It was not practicable to reproduce these charts in the Journal, Publication Committee.

DIRECT CURRENT COMPENSATORS FOR BALANCING ELECTRIC CIRCUITS.

By H. M. Biebel.

Read before the Electrical Section, W. S. E.,
February 15, 1907.

A direct current compensator is a device whereby one or more neutral wires can be introduced into an ordinary two wire circuit, these neutral wires making it possible to obtain circuits of proportionately lower voltage. The use of a D. C. compensator set, makes it possible to generate direct current at a comparatively high voltage and to deliver it for use at a lower voltage, thus combining the cheapness of high voltage transmission with low voltage receiving or translating devices. It is not the only way of obtaining a three wire system, but it is the only way of obtaining a four or a five wire system, should such a system ever come into general use, which becomes possible when the latest type of incandescent lamp is considered in small units.

The D. C. compensator for a three wire system originally consisted of two machines coupled together mechanically; one machine of a voltage equal to that of the supply circuit and the other machine of a voltage equal to one half that of the supply circuit, the schematic diagram being shown in Fig. 1. The upper of the two machines of the compensator set is of a voltage equal to that between positive and negative, which we may assume at 220 volts and the lower machine is a 110 volt machine. If a load were connected between the negative and the neutral wire, the low voltage machine would operate as a generator being driven by the high voltage machine which obtains its energy from the main generator. If the load or the excess of load were between the positive and neutral wires the low voltage machine would operate as a motor driving the high voltage machine as a generator.

It will be seen at once that the low voltage machine must be of a capacity equal to the probable or the figured unbalanced load and the high voltage machines must if anything be larger. This means that we are using two machines of say 10 k. w. capacity each to balance a load of 10 k. w.

This type was soon superseded by the present design in which two machines each of a voltage equal to one half of the voltage of the main generator, are coupled together mechanically, preferably with their shafts in line and connected by a suitable coupling, the two machines being mounted on a suitable sub-base. The two armatures are connected in series across the circuit, the schematic diagram being as shown in Fig. 2, where all field windings are left out for the sake of simplicity.

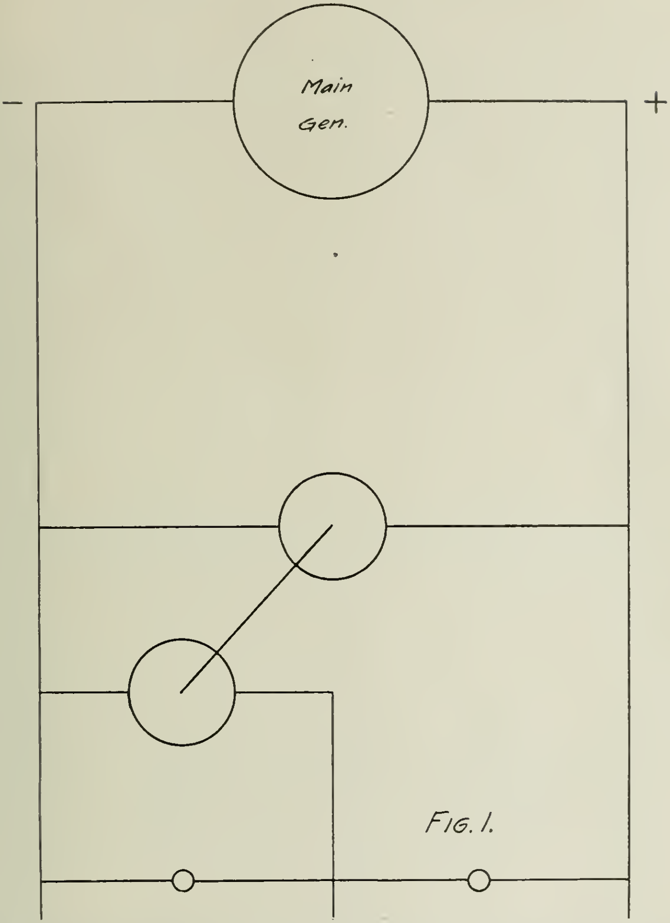


FIG. 1.

If we assume that there is no load on the main generator, and we start up the compensator set by means of a suitable starting box, we shall have the two machines running at their normal, no load speed, both operating as motors, and only enough current flowing through the armatures to keep them rotating at their normal speed. If loads are connected between the neutral wire and the positive and negative wires respectively, the loads on each side of the neutral being equal, there would be no change in the operation of the compensator set. If however, the load on one side of the neutral, say positive to neutral, should become greater than that on the other side, the machine connected between positive and neutral would operate as a generator being driven by the other machine operating as a motor. This action may be explained as follows:

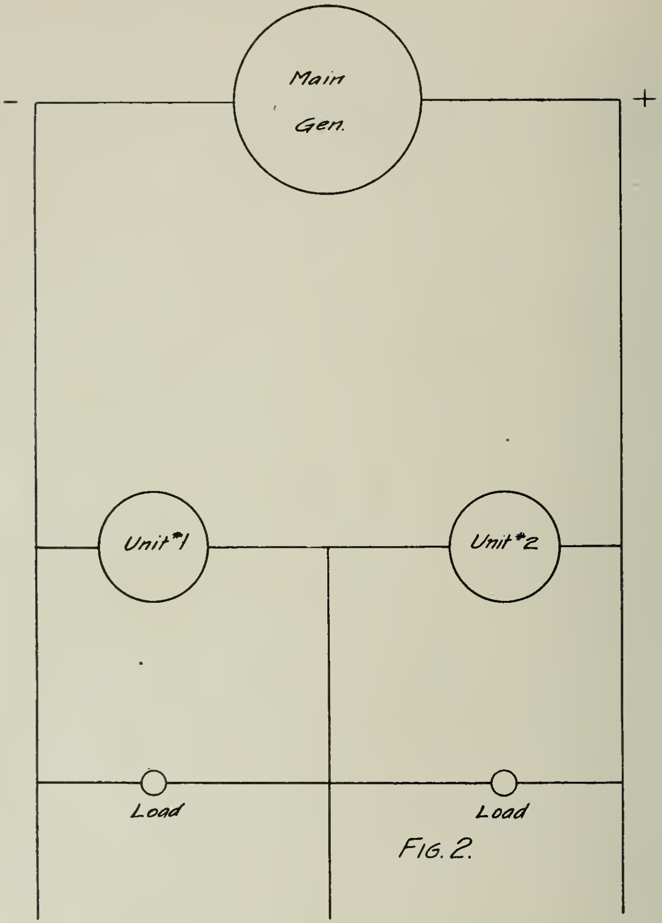


FIG. 2.

Assume that we have first a two wire main generator and a three wire distributing circuit with two banks of incandescent lamps connected between positive and neutral, and between neutral and negative wires. Assume that the load between positive and neutral has a resistance of 1 ohm and that between neutral and negative has a resistance of 2 ohms. The total resistance from positive to negative wires is therefore 3 ohms, and on a 220 volt circuit we would get a current of $\frac{220}{}=73.3$ amperes. The voltage drop from positive to neutral would be 73.3 volts and from neutral to negative would be 146.7 volts. If now a compensator set as shown in Fig. 2 were connected to the three wire system, it will be seen that unit No. 2 will be connected to a circuit whose voltage is lower than its own, while unit No. 1 will be connected to

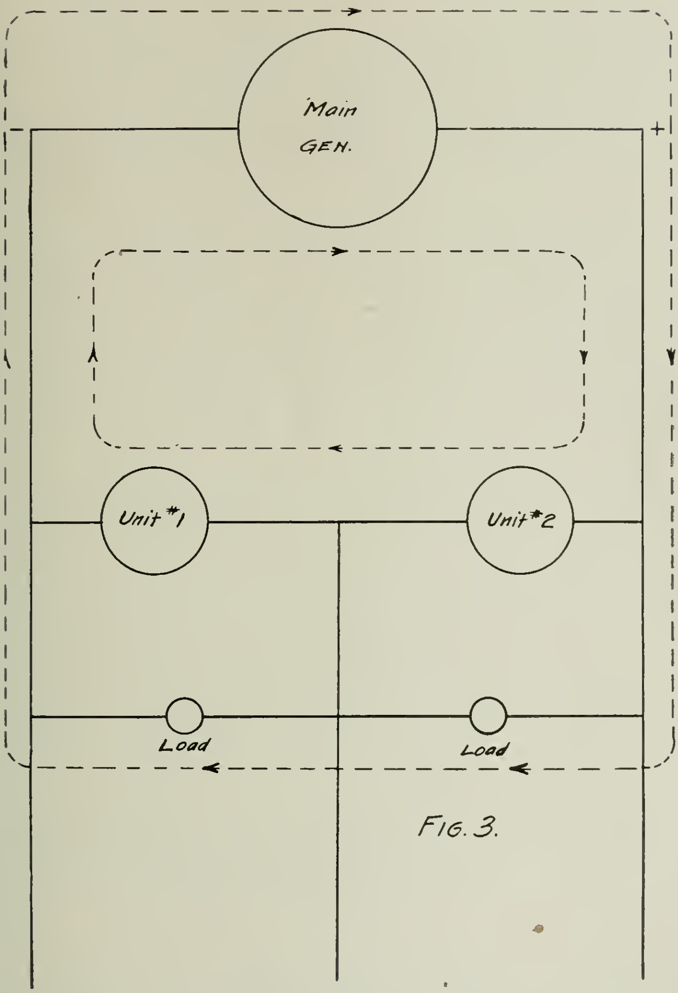


FIG. 3.

a circuit whose voltage is higher than its own. Therefore, unit No. 2, will act as a generator, being driven by unit No. 1, which will continue to operate as a motor, only operating at a heavier load. The location of the excess of load with reference to the neutral will determine which unit of the set will operate as a generator.

The current paths of the three conditions which can occur with such a compensator set are shown in the following figures:

Fig. 3. No unbalanced load, both machines operating as motors.

Fig. 4. Load on each side of the neutral, larger between positive to neutral than between neutral to negative.

It will be seen that the current flowing in the neutral wire is equal to the sum of the generator and of the motor currents and is

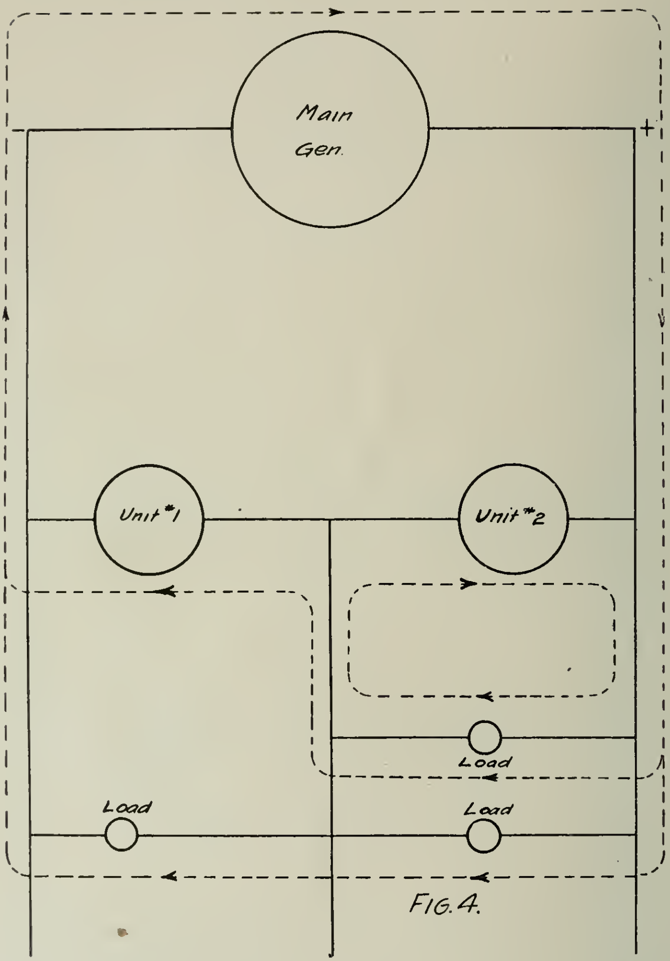


FIG. 4.

also equal to the difference between the currents carried by the loads on either side of the neutral at their respective voltages (which way or may not be the same and equal to one-half of the line voltage.)

The current in the unit operating as a motor will be some what larger than that flowing in the unit operating as a generator, as the motor must supply the armature losses of both machines. It will be seen that smaller units can be used in this compensator set than in the original type as here both motor and generator current is used to balance the excess load. Each machine must be able to operate as a motor or as a generator, according to whether the excess load is one side of the neutral or the other. If for example we have an unbalanced load of 50 amperes, the excess being first on one side of the neutral and then on the other, each unit must be able to operate properly between the limits of 20 amperes output as generator to 30 amperes input as motor, the speed and voltage remaining practically constant. The brushes of course, must be in one position for all loads, and it will easily be seen that the limit of output in a compensator set is given by sparking, rather than by heating.

The question of the transference of energy by a compensator set is an interesting one, and may be briefly touched upon here. This transference of energy by the compensator set results in a heavier load being thrown upon the main generator, than would be the case if no compensator set were used. Assume a resistance of 1 ohm and one of 2 ohms connected respectively between positive and neutral and between neutral and negative wires. If no compensator set be connected, the total current on a 220 volt circuit, would be 73.3 amperes and the load on the generator would be $\frac{220\times220}{3}=$ 16.13 k. w. If now we connect a compensator set and get an exact division of voltage the loads would be as follows: $\frac{110\times110}{1}+\frac{110\times110}{2}=18.15$ k. w., or an increase of 12 per cent. The losses in the field windings and in the armatures are not considered as a "load" on the machine in this connection.

If we have resistances of 1 and of 3 ohms we would have 12.1 k. w. and 16.13 k. w. respectively or an increase of 33 per cent. With resistances of 1 and 4 ohms we get an increase of 57 per cent., and with resistances of 1 and 10 ohms we get an increase of 203 per cent.

Shunt Wound Compensator Sets.—A shunt wound compensator set with the fields of the two units in series or in parallel between the two outside wires, will not give good regulation owing to the I. R. drop in the armature winding of the unit operating as generator and the drop in speed of the unit operating as motor, as the load increases.

The regulation of a shunt wound compensator will be improved by cross connecting the shunt fields so that with unbalanced loads the field of the unit which is operating as a motor is connected to a circuit having a voltage lower than its own, thus weakening the motor field, increasing the speed of the set, and increasing the voltage of the unit operating as a generator. At the same time the field of the generator unit is connected to a circuit whose voltage is higher than its own, thus strengthening the field and resulting in a still further increase in the generator voltage. Exact balance can be obtained in a shunt wound compensator by connecting the two fields in series and placing between them a small rheostat, the lever arm of which is connected to the middle point of the two armatures. By moving the lever away from the middle point so as to strengthen the generator field and weaken the motor field, we can get an exact balance of voltage for that condition of load. If now the excess load should suddenly be shifted over to the other side of the neutral, the difference between the voltages on the two sides of the neutral would be quite large, as the inherent poor regulation of the shunt wound compensator set, is made worse by the strengthened motor field and the weakened generator field. This style of connection will give good results where hand regulation of the rheostat is not objectionable and the load changes are not so sudden but that they can be followed up closely by the attendant.

A machine having two independent armature windings and two commutators on the armature can be used as a compensator set, but will not give close regulation. The curve B-B, Fig. 5, shows the voltage difference obtained on such a compensator unit of 30 k. w. capacity. This difference being 11 volts at full load. The curves A-A show the voltage difference obtained on an 8½ k. w. shunt wound compensator set with the fields criss-crossed, the maximum voltage difference being 8 volts.

In order to obtain automatic regulation and practically equal voltages on each side of the neutral under all normal conditions of unbalanced load, it is necessary to use compound wound units. There are a number of different ways of connecting the shunt and series coils, the usual method being to connect the series coils in the armature circuit and the two shunt fields in series across the outside wires. When starting up, both units will operate as differential motors, but upon being thrown into circuit and any unbalancing of load occurring, the unit then operating as a generator will be a cumulative compound wound machine. By proper adjustment of this compound winding on both machines we can get

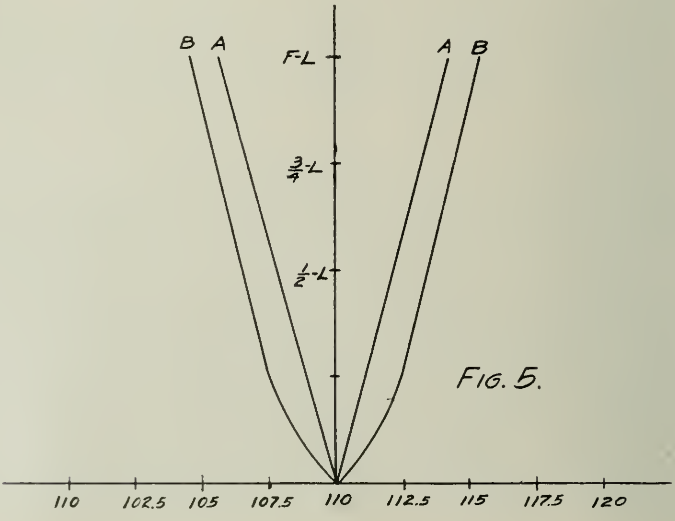


Fig. 5.

a practically constant voltage division up to and well beyond the normal capacity of the compensator set. It may be noted in passing, that as the motor current is greater than the generator current the differential action on the motor will be greater than the compounding action on the generator. The speed of such a compensator set will be higher at full load than at no load, which means that at full load the motor is operating at a lower point of its saturation curve than at no load, and if this differential action is carried to an extreme point by reason of excessive overloads, a point may be reached where the motor will "spill over:" that is, the motor will attempt to reverse its direction of rotation. One way of overcoming this tendency is to short-circuit the series coils of both machines when a certain current value had been reached, or to short-circuit the series coils of that unit operating as a motor. The first is the simpler method but results in a greater unbalanced voltage than would be the case with the second method. The first method requires a double pole switch normally held open, actuated by an overload coil connected in the neutral wire. When this switch is released it closes, short-circuiting the series coils of both machines. The second method requires a reverse current relay which operates to close the circuit through either one or two solenoids, which in turn will act to close a switch or a "circuit closer," which short-circuits the series fields of the unit, operating as a motor. If the excess of load shifts to the other side of the neutral the current in the neutral will be reversed, the reverse current relay will operate to take off the short-circuit on the one unit and then short-circuit the series coils of the other unit. A new method of connection has lately been used which overcomes this trouble and requires no short-circuiting device whatever.

Efficiency: The efficiency of a compensator set is calculated as follows, this method having been first shown in print by Mr. C. T. Wilkinson:

Let $2V$=line voltage.
I_M=motor current.
I_G=generator current.
C_s=shunt current in each unit.

Then the output of the compensator set will be, $V(I_G+I_M)$ and the input $I_M \times 2V + C_s \times 2V$ and the commercial efficiency of the compensator set will be,

$$\frac{(I_G+I_M)V}{2V(I_M+C_s)} \text{ or } \frac{I_G+I_M}{2(I_M+C_s)}$$

Taking actually obtained figures for the motor and the generator currents and calculating the efficiency from the above formula, we find that it is very nearly the same as that of either unit by itself. The commercial efficiencies of a line of compensator sets varying from 1 k. w. to 150 k. w. capacity will vary from 78 per cent to 92 per cent.

Protction of compensator set and of lights.—The question of how to protect the compensator set against excessive overloads, and how to protect the lamps against the failure of the compensator set may be answered in several different ways, depending upon whether the lamps can be cut off the circuit or not, and whether the compensator set must be kept in circuit at all hazards or not. When the lamps can be cut off the circuits, a circuit breaker with an overload release coil connected in the neutral wire can be used where the compensator set gives good regulation. Where a shunt wound compnsator set is used, where the difference between the voltage on each side of the neutral is a measure of the unbalanced load, a differential coil can be connected to the circuit, so that when the voltage difference exceeds a certain value this differential coil will close a circuit through a tripping coil on the main generator circuit breaker or on the lamp feeder circuit breaker. The ordinary no voltage release coil on the starter will protect the compensator set against trouble after a shut down due to momentary cessation of voltage.

To protect the lamps against the danger of excessively unbalanced voltages due to unbalanced load if the compensator set should accidentally shut down, the handle or lever of the starting box can be arranged so as to make a connection, while returning to its starting position, such that a tripping coil on the main circuit breaker shall operate to open them, thus cutting the lights off the circuit as the compensator set shuts down.

Our own recommendation has always been to fuse the compensator set at 100 per cent. overload, and not to use circuit breakers or special tripping devices, or in other words, protect the lamps rather than the compensator set. A large number of compensator sets have been installed, connected in this way, and so far no trouble from this source has been reported.

The requirements which a good modern compensator set should be able to meet are as follows:

First. Easy to connect and easy to throw into circuit.

Second. Practically absolute balance at all normal loads without rheostat adjustment.

Third. Easy to operate two or more sets in parallel.

Fourth. Standard stock parts used throughout.

When to use a compensator set:—Where it is desired to operate 110 volt lamps on a 220 volt circuit and the lamps can be so wired that the loads on each side of the neutral will be approximately the same, a compensator set will enable the installation to operate successfully. Its capacity need be only a small per cent. of the total load subject to unbalance, say about 10 per cent., and this might even be reduced to 5 per cent. where the lamps are well balanced.

If the load of any given generating station could be arranged so

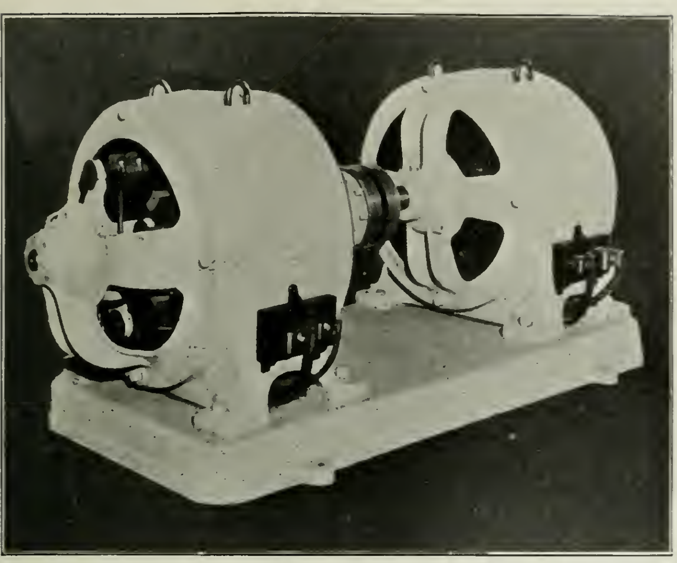


Fig. 6.

15 kw. Compensator Set.

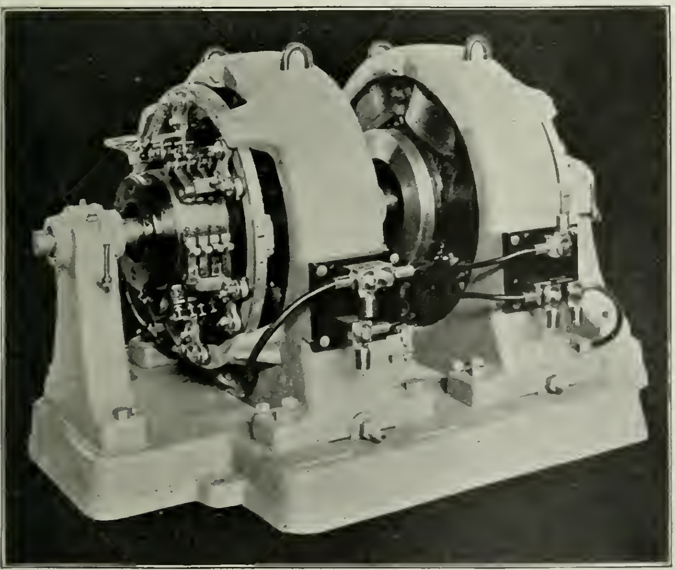


Fig. 7.

125 kw. Compensator Set.

that the motor load would be on one set of feeders and the lamp load on other feeders, the compensator set could be installed at or near the center of distribution of the lamp load, and the feeder drop could be taken care of by the main generators, the compensator set simply dividing the voltage obtained at the center of distribution. Any unbalance of voltage which would exist on the lighting mains would be due to the compensator set itself.

DISCUSSION.

Mr. C. A. S. Howlett—There is one point about the compensator that it not usually understood as well as it might be, and that is its simplicity. As a rule the average person contemplating using the compensator thinks he is getting some complicated connections and operations that no one knows anything about.

I will cite an experience we had in connection with a small plant to show that it is not complicated. In a small city of about 400 inhabitants, where they put in a 3-wire system, the generator as well as the compensator was bought f. o. b. cars. The man who was to put in the machinery, was an ordinary creamery operator; he owned and controlled a typical country creamery, and he expected to install this compensator, and connect and operate it successfully, although he had never had any experience in the electric lighting business. We cautioned him, and told him that even though he installed the machinery and connected it up, it would be wise to have someone examine the connections before the apparatus was put in operation. Finally, the last time we cautioned him, he said that the apparatus had been in operation for a month and had given no trouble whatever! So we claim that if a farmer can install, connect and operate a compensator successfully without trouble, it cannot be as compliacted as the average person wants to think it is.

Mr. C. G. Atkins—I was in hopes Mr. Biebel would go a little further and tell us about the three-wire machine that the Western Electric Co. is about to put on the market, as compared with the Westinghouse and other makes.

Mr. Biebel—The three-wire generator is a little out of my line, and as this is a compensator paper I left the three-wire machine for the discussion.

The original, and I may say well established, system of three-wire generators is that invented by Dobrowolski with a choke coil connected to two points in the armature, 180 electrical degrees apart, properly applied to multipolar machines, and having a loss in the choke coil whether there is any current flowing in the neutral wire or not. The balance, of course, on that three-wire generator is not perfect, depending to a certain extent upon the size of the choke coil. In the Western Electric Company's three-wire generator a second armature winding is made use of, properly connected and properly applied. It is easy to figure out the connections for the two-pole machine, but for the multipolar machine the connections are somewhat complicated. The voltage generated between the brushes of any dynamo is dependent upon the style of winding, whether series or loop and beyond that, upon the number of turns in the winding. If, now, we connect another winding having half the number of turns that the main winding has, and have it on the same armature so it will cut the same number of lines of force you will get half the voltage. By connecting two of these windings at 180 electrical degrees apart, you will get, on the 250-volt machine at the terminals of these windings 125 volts, and by connecting one end of this winding to the main winding, and the other to a collector ring yu will have a division of voltage. At the collector ring you will have 125 volts, where you will have 250 olts on the brushes of the machine. The distinction, as far as I have gone into the matter, is in the fact that no energy is lost in this winding until the current flows, whereas in the other winding there is a loss of energy. It is small but it is there. The inherent defect in the machines is, that as the load increases the unbalance becomes greater. There is no way in which a three-wire machine can be made to give absolute balance of voltage with unbalanced loads on the system. The trouble rises from the fact that you have only one magnetic circuit, and whatever you do to one side you do also to the other. That is one of the reasons why a one-frame compensator set will not give good regulation, and why a two-frame set will give absolute regulation; the main point being to have such windings applied to the machines as will give practically absolute automatic balance at all conditions of normal and even of excessive load, either on one side or the other.

The question of when to use a three-wire machine or a compensator set depends upon the character of the load and upon the requirements of the engineer. A point that has come up just lately, might be of interest here; namely, the use of the latest type of lighting units—the 3.1 watt lamp or the still later type, the 1 watt per candle lamp—in which any variation of voltage from time to time during the day is not conducive to long life, a three-wire generator would not give the lamp the proper voltage unless hand regulation were resorted to, and throw-over switches were placed on a few small circuits, enabling these loads to be thrown from one side of the neutral to the other in order to balance the voltage exactly. With the compensator set compound wound, properly adjusted,—where the regulation is within 2 per cent. guaranteed, and is usually absolute,—there would not be that danger, and whatever voltage was given by the main generators,—which of course can be properly compounded to get practically the same voltage at the center of distribution,—it would be divided into practically one-half on each side of the neutral wire, and would of course be what is required by the lamps.

Mr. Howlett—The question of the three-wire generator brings to my mind a contemplated plant. In a plant where two generators of good size and one compensator are being operated satisfactorily, it is desired to make an addition to the generator equipment. The parties are contemplating putting in a three-wire generator to run in multiple with the standard type generators, the complete system to be run in multiple. Such a system would work nicely as long as the compensator is large enough to take care of the unbalanced load, because they would get the benefit of the absolute balance, and would get their three-wire addition without buying another compensator.

Mr. Chas. A. Pratt—The original compensator consisted of a unit of full voltage directly connected to one of half voltage. That was first brought to my attention about ten years ago. One of the first of the machines which the Western Electric Co. produced was installed by myself in the plant of R. R. Donnelly & Sons. I think it was a 12 k. w. machine and that machine is still running, to the best of my knowledge. The regulation was within the requirements for factory purposes, but was not perfect. Later I installed in another place one of the single frame machines, with results which were just what were expected at the time. The regulation was not so good as in the previous machine, but since the load on the two sides was largely on the motor end, it was good enough for the purpose required.

In this connection I think we must keep in mind the fact that the compensator where used is considered by the person who uses it, as a necessary evil, to be avoided if possible. In the course of my experience I have installed quite a number of compensators, but have never put them in if there was any other way out. If a two-wire system could not be worked satisfactorily, my advice was to put in a compensator.

Mr. A. J. Cline—In the three-wire machine how much additional capacity is allowed in the generator? The compensating effect, it seems to me, is being taken from the generator and bringing overload on it without (as near as I can find out) the manufacturer putting any more into the machines. Some are guaranteed to take care of 25 per cent. unbalanced load continuously. Has any provision been made for taking care of the heating effects, or is that feature being ignored? One company states that it will use the standard machine and put additional balancing windings on it, still guaranteeing the standard heating limits. It would be interesting to know what is to be the practice.

Mr. Biebel—As I understand the question, I think the answer would be that the windings are designed simply to take care of the additional heat generated in the armature, and that there is no increase in the capacity. As far as I can see it, it is merely a question of design. If you buy a 100 k. w. two-wire generator, you receive certain guarantees as to temperature rise under continuous operation at normal load and speed. If you wish to buy a three-wire generator to meet the same requirements with regard to normal two-wire operation, with the added feature of being able to take care of 10, 15 or 20 per cent. unbalanced load, the designer has to provide for that feature. He will have to introduce certain new features into his machine, and will have to make certain changes. In general it will make the machine slightly larger, in order to have it meet the same guarantees as before.

Mr. Howlett—I have in mind a contract I saw recently for some three-wire generators where the heating was not changed. The heating was the ordinary 40 Deg. rise, and they guaranteed the unbalanced load as 25 per cent. but there was no change made in the k. w. capacity of the generator. The generator was sold for a 200 or 300 k. w. but the capacity of the generator was not decreased by the amount of the unbalance; it was kept up to normal. From the manufacturer's side I understand it was necessary to use a little larger machine than a standard two-wire machine, but from the customer's standpoint they used a standard machine.

Mr. Geo. H. Rowe—I understand the slot depth has to be increased in order to accommodate both windings. How much would that add to the trouble in making repairs in case one of the windings burned out?

Mr. Biebel—That question is again one for the designer to take care of in the first place, and to arrange the windings so that as far as he can prevent, there will be no burn-out.

Mr. Atkins—In my work I frequently find that an operating engineer must be pacified by the designing engineer as to why we do not put in as many compensators as generators. Of course there is no reason for it, but I have wondered where the operating engineer received the idea he must have as many compensators as generators. I have had to pacify two first class operating engineers in the past year.

Mr. Biebel—I have never happened to run across any such cases.

Mr. Howlett—As a rule it is quite difficult to give them the proper assurance that a small compensator will handle the equipment of a large power plant. They cannot seem to grasp the idea, and they are "doubting Thomases" for a long time after the plant has been accepted.

Mr. Atkins—I was wondering whether it might not have been a question of salesmanship. But, seriously, I was told, in connection with one plant on which I was retained, that the salesmen of two companies had the operating engineer primed and set, and he was determined that he was going to have as many compensator sets as generators.

Mr. Howlett—As a general proposition, if there is any trouble about an equipment, it is the salesman's. Whether the salesman is entitled to the criticism, of course it is hard to say.

Mr. D. W. Roper—In the diagrams displayed on the screen there were a number of schemes of connection shown, followed by several views of machines which were said to be superior in their operation to the machines shown in the diagrams. I would like a little information in regard to the scheme of connection in these machines by which perfect regulation is obtained.

In operating a three-wire system (for instance, one in this city) we find that, owing to the drop in our feeders, in order to secure balance at the feeder ends with the unbalanced load, it is necessary to unbalance the voltage at the generating station. That is, the pressure must be several volts higher on the side which has the larger current. Is it possible in any of the schemes which have been shown for compensators to *over-compound* so as to secure that effect of higher voltage on the side which has the greater load.

Mr. Biebel—What would be the object in that latter? Why should you want to over-balance?

Mr. Roper—In order to deliver a balanced voltage to the customer at the feeder end.

Mr. Biebel—That really is not necessary in the compensator set, because, up to the normal capacity of a well designed compensator set, it will divide the voltage equally, or practically so, within 2 per cent. That is one of the points I tried to bring out; on the ordinary two-wire machine you can put a compensator set at the end of the feeder and it will divide whatever voltage there is at the end. Assuming that you start with a very light load and then, perhaps due to some other load, the voltage rises at this point (indicating on diagram). A compensator set will divide that voltage equally or to within 2 per cent., so that you really would not have any occasion to over-balance.

Mr. Roper—I am talking about the problem of installing a compensator set in a sub-station, and where you have a variable load at the end of your feeder. The problem you describe is installing the compensator at the end of the feeder. In a system in the city there are a number of locations, in the lighter load districts, where we have that condition; where the load is unbalanced quite frequently, and it is almost impossible to balance it for all hours and conditions of load. We have to unbalance the bus in the substation to secure an equal voltage at the feeder ends. The unbalanced load may vary at times, and it was for the purpose of finding whether there was an automatic machine for that purpose that I put the question.

Mr. Biebel—The compensator sets, as built at present, have been designed only to divide the voltage and not our balance. So far, we have had no request for any such compensator set, and simply content ourselves with making this exact voltage division.

I believe the other question was with regard to the exact voltage balance obtained. The schematic diagrams show the current paths. I did not show any windings to avoid confusion. We can get regulation to within 2 per cent. in any compensator set, where we use two compound wound machines of equal voltage, by proper adjustment of the strength of the series windings.

Mr. R. E. Hellmund—It might be of interest to compare the practice of Germany and of this country.

In Germany the three-wire system and the compensator are more frequently used than in this country. There are two kinds of Central Stations in which the German engineer frequently employs the three-wire system when another system would be used here:

First, power plants for small communities. In such plants it is customary to use 440-volt D. C. between the mains, and 220 volts for the lamps, while here the A. C. plant is generally preferred, with 110 volts for the lamps. There are various reasons for this. In the first place, I think engineers in this country are skeptical as to the quality of the 220-volt lamps, while in Germany the 220-volt lamps seemed to give satisfactory service. Another and more important reason may be the fact that villages and small towns in America are not as concentrated, as a rule, as in Germany, and therefore here the transmission system calls for a higher potential than may be employed with a three-wire D. C. system. Still another reason may be the fact that there was for many years no satisfactory single-phase A. C. motor (like the Wagner motor) in the German market. This, of course, led to the use of a D. C. system in all casese where a limited use of motors had to be considered, but where the power used by motors is not sufficient to justify the use of an A. C. polyphase system.

Second, the three-wire system is much used in Germany for the lighting and power systems of large buildings and factories, while here in America, especially in New York, the largest buildings are generally equipped with 110-volt two-wire D. C. plants. Although it may be claimed that the two-wire system is simpler than the three-wire system, this advantage seems to be insufficient to counterbalance the great saving in copper that is gained by the use of a three-wire 2x220 volt plant, or even by a three-wire 2x110 volt plant.

With reference to the comparative use of the three-wire machine and of compensators in Germany, it seems that the compensator is used more frequently. At a rough guess, I think that in 75 per cent. of all cases the compensators are used. Even the Allgemeine Elektrizstats Gesellschaft, which owns the three-wire machine (Dobrowolski patent), employs, in the majority of cases, the compensator. Generally the three-wire machines are used.in small stations only.

Mr. Howlett—I would ask Mr. Hellmund if he knows why it is that, after developing the three-wire generator in Germany, it has not been used more extensively there?

Mr. Hellmund—I do not know of any reason in particular, but the following facts may have some bearing on the question: First, the three-wire system is used much more generally in Germany, especially in cases where it is not possible to balance the load very well. In such cases, of course, it is better to use the compensator than the three-wire system. Second, the three-wire system is used there more frequently in plants of comparatively large capacity. The compensator is of course to be preferred in such cases. Third, as a rule the German is very particular about the quality of light he receives from the power plant. The variations and inexactness of potential so frequently furnished by the power plants in this country would not be accepted by the German customer. This feature may have had an influence on the use of the compensator, since it will give an exact potential for any load distribution, while the three-wire machine can never give an exact division of potential for a very unbalanced load,

CORRECTION

In the paper on Swing Bridges in February issue on page 28, discussion by Mr. C. F. Loweth, first and second lines should read "It is *possible* to make satisfactory swing bridges." Please note and make change in your copy of the JOURNAL.

IN MEMORIAM.

Henry Clinton Draper, M.W.S.E.

May 3, 1903.

Henry Clinton Draper was born in Louisiana, Missouri, on February 3rd, 1845. His boyhood was passed in that vicinity, his first employment being as a printer with a Louisiana newspaper. In 1866 he joined an engineering party making surveys for the Louisiana and Missouri River Railroad, which later became a part of the Chicago and Alton Railway. He entered their service as rodman, and with the exception of two years, was in the continuous service of that Railway, or its leased and subsidiary lines, for thirty-five years, ending with his last illness.

During the two years referred to, 1871-1872, he was engaged in the construction of turnpike roads in Pike County, Missouri. In 1872 he accepted a position as rodman on the St. Louis, Keokuk and North-Western Railway, then doing some construction work. This road was also later made a part of the Chicago and Alton Railway and in their service he was promoted to levelman; later to Assistant Engineer; then to Division Engineer of the Western Division under Chief Engineer H. K. Booth. In 1888, upon the death of Mr. Booth, Mr. Draper was made Chief Engineer of the Chicago and Alton Railway, remaining in that position until the sale of the road to the Harriman interests in 1901, when he was succeeded by H. F. Baldwin. Mr. Draper was offered the title of Principal Assistant Engineer, but resigned to take charge of the construction of the Missouri Pacific Railway, between Booneville, Mo., and Jefferson City, Mo. At the completion of that work he was engaged in a consulting capacity by the Mississippi Valley Trust Company of St. Louis, investigating and reporting on various projects which they proposed to finance. This was his last active work, heart trouble causing his retirement.

Mr. Draper had intimate and personal knowledge of every bridge, and culvert, every foot of right of way on the Chicago and Alton Railway, and his retirement from their service was a shock from which he never recovered. He had charge of the building of the great bridge over the Missouri River at Glasgow, Mo.; the Illinois River bridge at Pearl, Ill.; and was associated with Messrs. Parkhurst and Corthell in the building of the long Mississippi River bridge at Louisiana, Mo. Later this bridge was rebuilt under his direction, when heavier traffic and rolling stock necessitated it.

Mr. Draper was a veteran of the Civil War, having served for three years in the Union Army as a corporal in a regiment of Missouri infantry, detailed to capture guerrilla bands of rebels which infested the hills. He was honorably discharged at the end of the war, and was a member of the Geo. H. Thomas Post No. 5, G. A. R. until his death.

In 1871 he met and married Miss Ellen Strother of Ashley, Mo., who with three sons,—Daniel C., Harry L., and Robert S., and a daughter, Mrs. Harry J. Houghton, survive him.

He was honored and respected by all who knew him, as one of Nature's noblemen, and by the engineering profession as one of the authorities on railroad work, and his memory is mourned by a great number outside of the profession. He died at his home on May 3rd, 1903, of heart failure, technically aortic regurgitation.

(Signed) Robert Strother Draper.
Chason Winslow Brooks.

A. R. Eldridge, m.w.s.e.

January 17, 1907.

Archibald Ronaldson Eldridge was born in Americus, Ga., September 6th, 1867, and died in Chicago, January 17th, 1907.

His boyhood was passed in Americus where he attended the City High School. Later he went to the Baltimore City College, and from there to Rensselaer Polytechnic Institute, Troy, N. Y., graduating from the engineering department of this school in 1888.

He was variously employed on railway location and maintenance work on the Americus, Preston and Lumpkin Railway, now a part of the Seaboard Air Line, and the Alabama Midland Railway until 1891, when he entered the bridge department of the City of Chicago, remaining there two years. He was successively Assistant

A. R. ELDRIDGE.

Engineer Maintenance of Way with the Savanna, Americus and Montgomery Railway, and City Engineer of Saratoga Springs, N. Y. In 1900 he entered the employ of the Chicago, Burlington and Quincy Railway, going into the bridge department. He remained there until the time of his death, having risen to the position of Assistant Bridge Engineer of that system.

He was married at Utica, N. Y., September 30th, 1891, to Miss Minnie Kelly, who survives him, together with their two children, Agnes, age 13, and Howard, age 11.

He was a member of the American Society of Civil Engineers, the Western Society of Engineers and the Franklin Institute. Also of the University Club, the Chicago Rowing and Canoe Club, the Jackson Park Yacht Club and the South Shore Country Club of Chicago.

Mr. Eldridge was a man of great professional ability, of keen perception and sound judgment. These qualities, together with his knowledge of details, made his work in the design of large railway structures particularly valuable. He was possessed, too, of a genial and winning personality, a kindly consideration for all with whom he came in contact and an unfailing courtesy which brought him the lasting friendship of all who knew him.

(Signed) L. J. HOTCHKISS.
E. N. LAYFIELD.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF REGULAR MEETING, March 6, 1907.

A regular meeting of the Society (No. 599), was held the evening of Wednesday, March 6th, 1907.

The meeting was called to order about 8:20 p. m. with Vice-President Allen in the Chair and about 110 members and guests present. The Minutes of the meetings held February 6th and 20th, were read and approved.

The Secretary reported from the Board of Direction, that at the regular meeting of March 5th, there were elected into the membership of the Society the following:

	Grade.
J. Wyman Ludlow, Chicago	Active
Edwin Dinwiddie, Chicago	Active
O. E. Soot, Chicago	Active
James L. Mills, Chicago	Ttransfer from Junior to Active
O. A. Turney, Phoenix, Ariz	Active
B. W. Seymour, Chicago	Active
Edwin H. Cheney, Chicago	Active
A. D. Page, Chicago	Active
T. R. Minert, Chicago	Junior
Frank N. Savage, Chicago	Active

Also that applications for membership in the Society had been received from the following:

	Grade.
E. H. Freeman, Chicago	Active
Fred C. Harper, Chicago	Junior
George A. Pennock, Chicago	Active
George Bright, Elmhurst, Ill	Junior
Francis S. Peabody, Chicago	Associate
Josiah F. Pinson, Whitehall, Mont	Active
James H. Collins, Chicago	Active
Harry B. Gear, Chicago	Active
George W. Waber, Chicago	Active
W. J. Sullivan, Ladysmith, Wis	Active
Edward H. Ravenscroft, Chicago	Active
Chas. H. Theilkuhl, Chicago	Active
Hermann Gansslen, Chicago	Active

Mr. L. J. Hotchkiss, M. W. S. E., was then introduced, who read his paper on "*Some Details of Concrete Construction,*" which was illustrated with some lantern slide views.

Discussion followed from Messrs. Condron, Chamberlain, Hoyt, Strehlow, Ewing, Talbot, Andrews Allen and L. J. Hotchkiss.

Dr. W. Michaelis, Jr., M.W.S.E., was then introduced who read his paper on "*How to Prevent Failure in Concrete Construction.*" After the reading of the printed paper with some additional pages, the meeting adjourned at 11 p. m. without discussion as the hour was too late. The Chairman, Mr. Allen, requested that written discussion of those papers be sent in to the Secretary for use in the Journal.

EXTRA MEETING, March 20th, 1907.

An extra meeting of the Society (No. 601), was held Wednesday evening, March 20th, 1907.

The meeting was called to order about 8:15 p. m. with President

Abbott in the Chair and about 60 members and guests present. There was no business to bring before the Society, so Prof. L. P. Breckinridge, M.W.S.E., was introduced, who gave *"A Review of the U. S. Geological Survey Fuel-Tests under Steam Boilers."* This paper was printed and sent out in advance, so it was not read *in extenso* by the author, but was abstracted and commented upon in a verbal presentation of the subject.

Discussion followed from Messrs. W. L. Abbott, Ray, Kreisinger, Barker, Moss, Holbrook, W. S. Huyette, Saxe, Way, C. S. McGovney, C. H. McClure, F. Chauvet, Bement and Prof. Breckenridge.

The meeting adjourned about 10:25 p. m.

REGULAR MEETING, April 3rd, 1907.

A regular meeting of the Society (No. 602) was held the evening of Wednesday, April 3rd, 1907.

The meeting was called to order at 8:20 p. m. with Vice-President Allen in the Chair, and about 30 members and guests present. The Minutes of the meetings of March 6th and 20th, 1907, were read and approved. The Secretary reported from the Board of Direction that at their meeting held April 2nd, the following were elected into membership:

	Grade.
J. Guy Huff, Nashville, Tenn	Active
E. H. Freeman, Chicago	Active
Fred C. Harper, Chicago	Junior
George A. Pennock, Chicago	Active
Francis S. Peabody, Chicago	Associate
Josiah F. Pinson, Whitehall, Mont	Active
James H. Collins, Chicago	Active
Harry B. Gear, Chicago	Active
James W. Waber, Chicago	Active
W. J. Sullivan, Ladysmith, Wis	Active
Edward H. Ravenscroft, Chicago	Active
Chas. H. Theilkuhl, Chicago	Active

Also that applications for membership had been received from:

Henry J. Sawtell, Chicago	Junior
G. F. Gebhardt, Chicago	Active
Ernest Edward Meier, Chicago	Junior
Grant Beebe, Chicago	Active
John C. Gustafson, Chicago	Junior
Wilbur M. Wilson, Ames, Iowa	Active
J. C. Thorpe, Urbana, Ill	Active
Fred Schumacher, Chicago	Active
E. T. Bent, Chicago	Associate
K. Hojgaard, Chicago	Active

The Secretary also reported the action of the Board of Direction, in the matter of searches made in the Library of the American Society of Civil Engineers. The following from the Proceedings of the A. S. C. E. of January, 1907, page 6, was read, in explanation of this subject:

"In January, 1902, the Secretary was authorized to make searches in the Library, upon request, and to charge therefor the actual cost to the Society for the extra work required. Since that time many searches have been made, and bibliographies and other information on special subjects furnished.

"The resulting satisfaction, to the members who have made use of the resources of the Society in this manner, has been expressed frequently, and leaves little doubt that, if it were generally known to the membership that such work would be undertaken, many would avail themselves of it.

"The cost is trifling, compared with the value of the time of an engineer who looks up such matters himself, and the work can be performed quite as well, and much more quickly, by persons familiar with the Library.

"Copies of all lists of references are filed, so that in many cases it is only necessary to make a typewritten copy, which reduces the cost of searches to a minimum.

"In asking that such work be undertaken, members should specify clearly the subject to be covered, and whether references to general books only are desired, or whether a complete bibliography, involving search through periodical literature, is desired."

The Secretary also referred to the index of searches made as shown on page 20 of the same issue of the Proceedings of the A. S. C. E., to better understand what searches had been made. He then stated that Mr. Brunner, as Chairman of the Library Committee, had written to Secretary Hunt, of the A. S. C. E., asking if the benefit of such searches could be extended to members of the Western Society of Engineers. The letter of reply, from Mr. Hunt, Secy., A. S. C. E., showing that such searches could be made for members of this Society, is here presented:

"Answering your esteemed favor of the 27th ult., I brought the matter therein mentioned to the attention of the Board of Direction of this Society at the meeting held on the 5th inst.

"I am directed to say that the Society will be very glad to furnish copies of the searches already made in its Library, or to be made in future, to any member of the Western Society of Engineers, who are not members of the American Society of Civil Engineers, who care to have them made, at the original cost of making the search.

"Copies of these searches are funished to members of the Society at one-half that cost.

"I beg to call your attention to the fact that the cost is really a very small one, the average cost of searches made to date being a little over $5, and in order to get this average the cost of one or two very expensive searches was used, so that for the average search the cost is considerably less than the figure named.

"I also wish to call your attention to the fact that in many cases these searches are not complete bibliographies on the subject named, inasmuch as they have been made for specially interested parties, and have been some times restricted to a few years, and in a few cases to certain particular periodicals, or indexes.

"There can be no doubt that this work is of great value to each original inquirer, and that in some cases the searches can be made available for other parties, but what I wish to make clear is that there can be no guarantee in ordering a copy of a search that it shall be a complete bibliography on the subject."

The Secretary also stated that the Board of Direction desire that any requests for such searches, for members of this Society, should be sent through the Secretary's office of this Society.

The Secretary then announced the recent death of Mr. Harmon Trueman, M.W.S.E., on Friday, March 22nd, 1907, from heart failure. On motion of Mr. Layfield, that a Committee be appointed to prepare a memorial of Mr. Trueman, the Chair appointed Messrs. E. N. Layfield and Arthur C. Smith.

There being no other business to bring before the Society, the Chairman stated that the paper for the eevning, *"A Colorado Mountain Reservoir"* By R. M. Hosea, M.W.S.E., Denver, Colo., would be read by the Secretary in the absence of the author. The paper was so read, with lantern slide illustrations, and was followed by some discussion from Messrs. Allen, Burdick, Warder and Storey.

The meeting adjourned about 9:40 p. m.

J. H. Warder,
Secretary.

MINUTES OF THE ELECTRICAL SECTION, March 15th, 1907.

A regular meeting of the Electrical Section (the 23rd), being an extra meeting of the Society (No. 600) was held the evening of Friday, March 15th, 1907.

The meeting was called to order with Mr. C. A. S. Howlett in the Chair and about 60 members and guests present. There was no business to bring before the Section, so Mr. J. M. S. Waring, Dist. Engr. of the Electric Storage Battery Co., was introduced, who read his paper on *"The Application of the Storage Battery for Lighting, Power and Railway Service."*

Discussion followed from Messrs. Junkerfeld, C. E. Freeman, Beck, Atkin, Howlett, F. M. Davis, Lake, Taussig, Roper and W. D'A. Ryan; with a closure by Mr. Waring.

The meeting adjourned about 10:00 p. m.

MINUTES OF MEETING, April 12th, 1907.

A regular meeting of the Electrical Section (the 24th), being an extra meeting of the Society (No. 603), was held Friday evening, April 12th, 1907.

As it was a stormy evening there was a smaller attendance than usual. The meeting was called to order about 8:10 p. m. by the Chairman, C. A. S. Howlett, with about 35 members and guests present. The Minutes of the preceding meeting, March 15th, were read and approved.

The Chairman then introduced Mr. Thos. Lambert, of the Chicago Telephone Company. He then surrendered the Chair to the Vice-Chairman, Mr. D. W. Roper, and excused himself from the meeting. Mr. Lambert addressed the meeting on *"Power Work as Related to Telephone Communication."* The paper was illustrated by blackboard sketches.

Discussion followed from Messrs. F. M. Davis, Roper, Cravath, L. W. Carroll, J. B. Thiess, Wm. Reid and Thos. Lambert.

The meeting adjourned about 9:45 p. m.

J. H. Warder,
Secretary.

BOOK REVIEWS.

An Extension of the Dewey Decimal System of Classification: Applied to the Engineering Industries; by Professors L. P. Breckenridge and G. A. Goodenough, Urbana, Ill.

The Engineering Experiment Station of the University of Illinois has just issued Bulletin No. 9 under the above title. Copies have been sent to members of the Western Society of Engineers, and it is hoped that they will be found useful.

The Dewey classification system has been used for several years by the Mechanical Engineering Department, University of Illinois, in connection with its card index of current periodical literature; also for the indexing of catalogs, drawings and miscellaneous material, and as the result of several years of labor on the part of students and instructors, the department has accumulated a valuable card index of technical literature; the number of cards now exceeds 20,000. Arrangements have been perfected whereby the Library of the Western Society of Engineers is furnished with duplicate copies of these cards referring to important articles on mechanical and railway engineering, and has now about 5,000 cards in its files. These are numbered according to the extensions of the Dewey system contained in the bulletin mentioned. The abbreviations for the various periodicals are the same as those given in the Engineering Index, Vol. IV. The Secretary will arrange to furnish members of the Society copies of these cards on special topics, if such are desired, at a very moderate price, to cover the cost of preparing them.

Members of the Society who care to avail themselves of the Society's card index or copies of them, or who have their own private indexes, will therefore find this bulletin helpful as a guide in classification.

It should be remarked that the present extension includes practically all branches of engineering industry. For the first time an adequate extension of the Dewey system for electrical engineering has been worked out. Bridge engineering, building, and metallurgy have also been somewhat extended. The bulletin as a whole is a self-contained classification covering the ground of engineering industry, and should prove of value to the engineering, manufacturers, and technical men of Illinois. It is a good piece of work that has been done by the State University.

The present bulletin, No. 9, also known as Vol. IV, No. 5, Part 1; Nov. 1, 1906, is a pamphlet of 72 pages, standard size, 6 by 9 ins., and is a notable advance over the first edition of only six pages, which was brought out a few years ago. The paper, typography and arrangement is most excellent; this pamphlet should be a valuable addition to the working library of engineers.

Graphical Handbook for Reinforced Concrete Designs By John Hawkesworth, C. E., Engineer with Raymond F. Almirall, Archt. D. Van Nostrand Company, New York, 1906. 8¾x11 ins.; 64 pages; 15 plates. Price $2.50 net.

This book contains fifteen plates with diagrams for use in designing the size and amount of reinforcement for floors, beams, and columns of reinforced concrete construction. These diagrams give the safe resisting movement for beams with percentages of reinforcing up to 3%, the resisting moment for slabs of different thicknesses reinforced in one direction, the bending moment in pier footings, the resisting moment of beams and slabs of depths up to 21 inches, position of the neutral axis, shearing resistance of beams, allowable load on columns with longitudinal steel reinforcement of various percentages, loads on hooped columns, various graphical multiplication tables, and a design of a reinforced concrete structure. The appendix gives the derivation of the formulas for rectangular beams and T-beams, for columns with longitudinal reinforcement, and for hooped columns, and also the requirements of the building code of New York City in regard to reinforced concrete.

The diagrams are well drawn and quite conveniently arranged for use. The limiting unit stresses are generally those prescribed by the building code of New York City, though the author has used the parabolic relation between stress and deformation in the concrete. In doing this he has failed to recognize that the ratio of stress to deformation is one-half as great at the vertex of the parabola as at the beginning, and hence that the straight-line value of the modulus of elesticity is not applicable. This oversight and the low value for the compressive stress in concrete specified have the effect of giving much lower strength to beams of medium reinforcement than would be accepted by many engineers, much lower strength, comparatively, than the results of numerous tests by various experimenters. The formulas given for hooped columns can not be said to be well established, and the diagrams for their strength are therefore of dubious value. The book would be better if the example of design of a reinforced concrete structure had been omitted, for the details are open to serious criticism. However, as a set of diagrams for calculations under the conditions assumed in the text and with limitations such as are suggested above, the book is to be commended for its simplicity, clearness, convenience, and practical value. Its limitations are largely those of the restrictions of the building ordinance used. A. N. T.

Practical Metal Turning: A handbook for Machinists, Technical Students and Amateurs. Jos. G. Horner; pp. 404 including index; 488 illustrations. Norman W. Henley Co., New York. Cloth, 8x5½ ins. Price $3.50.

This is an excellent work, though the style and some of the illustrations betrays its English origin. Certain terms employed do not sound natural to a Yankee, yet one acquainted with the subject would not be confused. He would find the book full of valuable information, if at all conversant with the subject. To a technical student, or a "prentice," eager to learn all he can of his craft, the book will be found pleasant reading. After the introduction, which explains the relation between the lathe shop and the other parts of a machine works. The subject matter is classed under Section I, The Lathe, Its Work and the Tools. Section II, Turning Between Centres. Section III, Work Supported at One End. Section IV, Internal Work. Section V, Screw Cutting and Turret (lathe) Work; and finally Section VI, Miscellaneous Matters, which includes Special Work, Measurements, Grinding, Tool Holders, Tool Steels (special) with Speeds and Feeds for Rapid Work.

The advent of these "High Speed Steel" cutting tools has introduced great changes in the output of the lathe shop over that of an earlier generation of workmen, and the instructions for the working of the steel for these cutting tools is very properly introduced at the end of the book. The applicances for holding the work, as chucks of various forms and designs, are interesting to one who recalls some of the difficulties experienced in his "prentice days;" and he thinks with regret, how he would have revelled in such a work as this in those early, eager and enthusiastic days, when to be put at lathe work, was counted as quite an advance, and almost as a "reward of merit' for previous good behavior in the shop. W.

The Six-Chord Spiral: By J. R. Stephens C. E., Denver, Col.: 68 pages 5 by 7½ ins., cloth $1.25, boards $1.00. The Engineering News Publishing Co., New York.

One of the essential conditions of an easy riding track is that the resultand pressure of the car body upon the rails should at all times be perpendicular to the plane of the track. It therefore follows that the super-elevation of the outer rail on curves should at all points be proportional to the degree of curvature. This is the fundamental principle which gives rise to the necessity for an easement between tangent and curves, and upon which the mathematical construction of the true transition curve is based.

There are two kinds of easement curves in use, viz.:

First: The True Transition Curve, based on the principle above stated, which has a radius of curvature starting at infinity and decreasing in proportion to the length of the curve till it becomes equal to that of the main curve with which it connects.

Second: The Compound Transition Curve, which is a series of compound curves, approximating more or less closely to the True Transition Curve. The little book here reviewed treats of a curve belonging to the latter class.

Since the elevation of the outer rail is calculated for a certain definite speed, it is a misfit for any other speed. Therefore, the adjustment of the super-elevation to the degree of curvature is at best but an approximation in the counter-action of centrifugal force. Experience has shown, however, that considerable variation may exist in the relation between super-elevation, curvature and speed without noticeably affecting the riding qualities of the track. An easement curve, therefore, that is reasonably close to the true transition curve is practically as good as the latter, and may preferably be used if it possesses other advantages over the true curve. The reviewer is not familiar with any method, heretofore published, treating of the compound transition curve that is as simple and elastic as the true curve. In this respect it appears that the author has added something to our knowledge of transition curves. His method is ingenious and simple and produces a curve coinciding so nearly with the true transition as to be practically identical. The formulas are few and simple. They can be easily memorized or written on the fly leaf of the field book.

The author's method is briefly as follows: He uses a spiral of six equal chords, whose arcs are circular curves, compounded at the chord points, and uniformly varying in curvature. The last arc coincides with the main curve. But instead of running the six-chord spiral by deflections to the chord points, he uses an auxiliary curve, which he calls a one-chord spiral. This one-chord spiral is a circular curve three-fourths the length of the six-chord and has a radius twice that of the main curve. It corresponds to the four intermediate chords of the six-chord spiral. It is run simply as a compound curve on the end of the main curve; four deflections being used which locate points opposite the chord points of the six-chord spiral, except at the center where the two coincide. By means of small lateral off-sets, which are readily determined, stakes are set on the six-chord spiral, while deflections are turned for points on the one-chord. The one-chord spiral, six-chord spiral and true transition curve, which the author calls the Track Parabola, all bisect the off-set between the tangent and main curve produced. The degree of main curve, length of six-chord spiral and main curve off-set are inter-dependent. The first is known and one of the last two must be assumed and the other calculated. The method is perfectly elastic and the use of tables is entirely obviated.

The book has been written for the practical man rather than for the students, as the formulas are generally dogmatically stated, and in some cases require considerable labor to evolve. The text is supplemented with numerous practical examples, and the application of the spiral to a number of special problems fully worked out. On the whole the work is very commendable. W. C. A.

Railroad Curve Tables: Containing a comprehensive Table of Functions of a One-Degree Curve with Correction Quantities, giving exact values for any degree of curve, etc., etc. R. S. Henderson, Chicago, 5 by 7 ins., 69 pages. Price $1.00, cloth bound. The Engineering News Publishing Co., New York.

A common feature in field books for railroad engineers is a table of sub-tangents and externals of a 1 degree curve, from which the value of these functions for a curve of any degree may be derived approximately by a process of simple division. By the application of certain corrections, given in an auxiliary table, results accurate enough for all practical purposes may be obtained. The method is simple and direct and there is much to be said in its favor. Curve computations, however, are of so simple a nature that special tables of this kind seem almost unnecessary. In this book very complete tables are given for applying this method. In addition to the above named functions, values are given for long chord, middle ordinate, and co-ordinates X and Y, for angles varying from 1 degree to 118 degrees. The usual feature of the book lies in the table of corrections. Only one table is given, applicable to all functions. This is made possible by using as argument of the table the numerical value of function of a 1 degree curve. There is thus no necessity for considering central angle or the nature of the function in taking corrections from this table. There is also a complete table of radii, a table of seven-place sines and tangents and several minor tables. Six or eight pages of formulas and methods, some of which appear to be original, complete the book. On the whole, the book is complete and sufficient for the application of the special methods outlined. The most serious criticism to be passed on it is in connection with the typography, which is poor. J. E. M.

Modern Milling Machines: Their design, construction and operation, by Jos. G. Horner. 9 by 6 ins.; pp. 304 with index; 266 illustrations and many tables. The Norman W. Henley Co., New York, 1906. Cloth, price $4.00.

Milling machines are essentially of comparatively recent creation, and their development and use seem to be coincident with the advent of the emery grinding tools. In a general way it may be said that milling machines may be divided into two great classes; one where the work is traversed under, or past the rotating cutting tool, and the other where the cutting head itself is traversed and the work is stationary.

Again the "mill," or cutting tool, may be a solid piece of hardened steel, fluted, to give a number of equi-distant cutting edges, or separate cutting tools of smaller size may be inserted and fastened to a revolving head; in either case the cutter revolves, that one after another of the cutting edges may be brought against the work. One great advantage of milling cutters is that as they consist of a number of cutting edges, which are intermittently engaged in cutting, they are thus not heated by the continuous cutting operation, which is the characteristic of the ordinary lathe tool. With a number of cutting edges of comparatively small section, which each remove but a small portion of metal, the life of each cutting edge is prolonged, and yet the economical removal of the metal is frequently greater than by other methods. Another great advantage of milling machines in machine shop work is that the "mills" may be made of such shapes that the finished work, i. e., that which has been "milled," may have a special and predetermined shape, and a great number of pieces of metal may be successively so shaped and all alike, or identical, within very narrow limits. It was the growth and development of the sewing machine and small arms manufacture, which gave the greatest impetus to the evolution and development of the Milling Machine Tools.

The book under review is full of illustrations of many forms of Milling Machines and Cutters, and of their applications. It also shows methods of holding the work to be "milled" and gives advice on the shaping of the cutters or mills, the spacing of the cutting edges, the rate of feed, etc. The hardening of these mills or cutters is another subject of importance, but properly belongs to books treating of the forging and hardening of tools.

The book as printed is a valuable addition to the class of practical works concerned with machine shop operation. The paper, typography and illustrations are all excellent. W.

Concrete and Reinforced Concrete Construction: By Homer A. Reid. Cloth; 6 by 9 ins.; 884 pp.; 715 illustrations. The Myron C. Clark Publishing Co., New York, N. Y. Price $5.00 net.

This book of 34 chapters covers the entire field of concrete and reinforced concrete construction, though the treatment of reinforced concrete is accorded a fuller space than the subject of plain concrete. The table of contents is extremely comprehensive and may be briefly summed up as follows:

Historical sketch of cement, its manufacture and applications to structural work; various classes of cement; Portland cement manufacture, properties, and tests; sand, broken stone and gravel; proportioning concrete, with a resume of the rules governing the mixtures to use, as set forth by Thacher, Gillette, Rafter, and others; mixing and placing concrete, with many practical notes and comments; cost of concrete, with itemized costs of the aggregates, the handling, the placing, the forms, etc.; finishing concrete surfaces; general physical and elastic properties of concrete, and of reinforcing metal; discussion of the proper disposition of reinforcement; mechanical bond; styles of slab and beam reinforcement; theoretical discussion of stresses and flexure in straight and curved members; theory of beams and columns, with statement and discussion of the formulas originated by Prof. A. N. Talbot, Capt. John S. Sewell, Ransome, Thacher, Hennebique, Coignet, Johnson and others; foundations, building, retaining walls, dams, conduits and sewers, tanks and reservoirs, chimneys, tunnels, railroad ties, fence-posts, piers, bridges, etc.; centering for arches; concrete building blocks..

While this work covers a very large field it does not slight any portion of that field; some subjects, which have attained a greater degree of standardization than others are accorded less space. Subjects like Theory of Beams, and Theory of Columns, concerning which there is still a great variation of opinion, are presented quite fully, the author not taking the responsibility of choosing among the great number of theories and formulas, any certain one which should be received as standard. While the widely diverging difference of opinion in the theoretical phases of reinforced concrete is lessening year by year, so that we may confidently look forward to a comparatively uniform view of this subject, yet the time for this has not come, and since standardization has not been reached, it is necessary for books on the subject to include all the leading views in regard to any phase, even though it is evident that time will discard most of these. It is this transitional element in the growth of reinforced concrete that compels an author, who wishes to cover the field at all thoroughly, to produce such a lengthy volume.

The last half of the book dealing with structures of concrete, plain and reinforced, presents examples from actual practice. For instance, chapter XXV, on Retaining Walls, 18 pp. in length, presents examples of various classes of retaining walls as erected both here and abroad with numerous illustrations showing the reinforcement, proportions, etc.

The author is not an exponent of any particular system of reinforcement, but shows examples of numerous works according to all the leading systems of construction, in vogue both here and abroad.

In conclusion, it may be said that though the book is rather large, it is not too heavy to be handled easily; the type is of good size; the illustrations are clear-cut and uniform, and the arrangement of the text is, in the main, logical. While this book is not a better one than several others on the market, either as regards the subject matter or its presentation, the fact that it is the most recent work will commend it to many readers, inasmuch as the subject of reinforced concrete has been undergoing a gradual change for some years, and the art has not yet solidified into definite standards of practice.

A. L.

DESIGN OF A RAILWAY BRIDGE PIER: By Charles Derleth, Jr., C. E., Associate Professor of Structural Engineering, University of California. Phamphlet, 6¾ by 10¼ in., 24 pp. Engineering News Pub. Co., New York. 1907. Price, 50 cents.

This paper on the subject of a bridge pier follows the old path in theory laid down by text books and engineers years ago, and is hardly in keeping with modern ideas.

Under the stability of the pier, the author considers the transverse forces, such as wind, ice thrust, current pressure, etc., and wholly neglects the longitudinal force due to friction, and the dynamic action of the moving load. With the penetration given, the stability against any combination of transverse forces need never be questioned. Especially is this true of a pier for a double track bridge resting on bed rock. However, the effect of the longitudinal force due to friction is of far greater importance, and if properly provided for, gives the entire structure a certain freedom from vibration during the passing of a moving load, which is very desirable. Moreover, this stability comes into play very often in bridges where the expansion rollers fail to act, or become clogged for some reason, and the writer knows of two cases where this, combined with the dynamic action of the moving load, has resulted in the opening of some of the horizontal joints in a pier.

The pressure on bed rock due to gravity alone, neglecting buoyancy and skin friction, is found to be 9 tons per sq. ft. This the author considers safe for concrete and bed rock, but he fails to give the limiting pressures in such cases. For sand he considers this pressure too high, so that a much larger caisson would be necessary to reduce the load on the sand. This may be true with small penetrations; but, all sand foundations should be put below any possible scour, so that the permissible pressure on sand should be dependent upon the penetration below the scour-line. In such cases pressures on sand have exceeded 12 tons per sq. ft. without yielding, and it can be shown that, for great penetrations in sand, with known co-efficients for friction, the entire load may be carried by the skin friction alone, similar to the grain in a deep bin being carried by the friction on the sides, alone.

The use of a steel caisson is questionable, owing to its excessive cost, as compared with wood or recent concrete caissons used for similar purposes.

The metal in the caisson is given at 13.5 lbs. per cub. ft. of caisson volume, which, at four cents per pound in place, equals 54 cents per cub. ft. of caisson volume. This is for the steel alone; and, when it is considered that the concrete used in filling the caisson will cost as much more, making a total of more than $1.00 per cub. ft. of caisson volume, the estimated cost seems high as compared with a concrete caisson costing about one half this amount. In neither case is the cost of sinking considered. J. W. S.

TRADE CATALOGUES.

"Practical Irrigation." Fairbanks, Morse & Co., Chicago, "No. 114" is an interesting and beautiful piece of printers' work,—beautiful from the typography, illustrations, paper, etc., and interesting from the subject itself and the valuable information contained therein. This is a standard size phamphlet 6 by 9 in. of 36 pages, and shows the various forms of pumps used to raise water for irrigation purposes, and the different motors and arrangements for operating the pumps, whether by air, steam or electric power. More and more it is shown throughout the country the very valuable results to be obtained by irrigation, but in many places the necessary supply of water cannot be secured by a gravity flow. But it has been shown in numberless cases that profitable results can be had by installing a pumping plant to elevate the water for irrigation from a lower level than the land that is to be watered. This may be from a surface stream, below the general level of the land to be irrigated, or it may be from subterranean water supplies. Having settled the question of the water supply, the next question is how it may be best raised to the required elevation to give a gravity flow where needed.

This phamphlet contains such illustrations and tables as to greatly help the solution of such problems. Thanks are due to Messrs. Fairbanks, Morse & Co. for such a book, and which *may be had for the asking.*—No. 114. W.

Jeffey Conveying Machinery for Sawmills, Lumber Mills and Wood Working Industries. Catalogue No. 57 B, issued by the Jeffrey Manufacturing Co., Columbus, Ohio, is a standard size phamphlet 6 by 9 in., 72 pages; filled with illustrations of various types of conveyors, and of their manifold applications. The pictures are so good that very little text is necessary to make clear to the reader the great economic value of installing some one of the many forms of conveying apparatus, which the Jeffrey Manufacturing Co. can furnish, whether it be in the specific line of manufacture stated in the title above, or in some other line of industry.

This Company was established in 1876, and in the last 30 years wonderful advances have been made by them in the application of their accumulated knowledge and experience, in the installation of one or another form of labor saving elevating and conveying machinery. W.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for February, 1907, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

Board of Examiners of Architects, 5th Biennial Report, with Laws, Rules of the Board, and List of Licensed Architects. 1907. Pam.

Tratman, E. E. R., M.W.S.E., Chicago.
- Proceedings, 40th annual convention, Master Car Builders' Association, 1906. Half roan binding.
- Statistics of Railways in the U. S., Interstate Commerce Commission, 1905. Cloth.
- Preliminary Report on Income Account of Railways in the U. S. for 1906. Pam.
- Railway Signal Association, Proceedings for 1907. Pam.
- Association of Ry. Supts. of Bridges and Bldgs. Proceedings for 1906. Pam.
- Association of Transportation and Car Accounting Officers, Bulletins Nos. 4, 5 and 6.
- Water Supply and Irrigation Papers, Nos. 182, 183, 185, 187, 188, 189. 6 Pam.
- Traveling Engineers' Association, Proceedings 14th annual convention, 1906. Flex. leather.
- Conditions Hydrauliques des Grandes voies Navigables du Globe; by E. L. Corthell. 1906.
- American Ry. Eng'g & M. of W. Assc'n, Bulletins 79, 82, 83, 85, 1906-7.
- Austrian Ry. Ministrial Order of Aug. 28, 1904, concerning Railway Bridges, Over-bridges and Approching Road-bridges, with iron or wood superstructures. Pam.

Smithsonian Institution, Washington, D. C.
- Annual Report, Board of Regents of Smithsonian Institution for 1905. Cloth.
- Annual report, U. S. National Museum for 1905. Cloth.

Illinois Board of Charities, Bulletins, October 1906 and January 1907. Pam.

South Park Commissioners, Chicago, Annual report for 1906. Pam.

M. C. Clark Publishing Co., New York, Concrete and Reinforced Concrete Construction; by Reid. 1907. Cloth.

MacMillan Company, New York.
- Problems of the Panama Canal; by Abbot. 2nd Ed. 1906. Cloth.
- A Text-book of Electro-Chemistry; by Max Le Blanc. 1907. Cloth.

Norman W. Henley Pub. Co., New York, Modern Steam Engineering; by G. D. Hiscox. 1907. Cloth.

D. Van Nostrand Co., New York. Graphical Handbook for Reinforced Concrete Design; by Hawkesworth. 1906. Cloth.

Engineering News Pub. Co., New York.
- Manual of Civil Service Examinations for Engineering Positions in New York; by Lewis and Kemper. 1906. Cloth.
- Design of a Railway Bridge Pier; by Dereleth. Pam.

Brookline, Mass., Water Board. Report of Water Board, 1906. Pam.

Strobel, C. L., M.W.S.E., Chicago, 4 bound volumes.
Water Supply and Irrigation Papers Nos. 53-63, 2 vols.
Report of seventh International Congress of Navigation held at Brussels, Belgium, July 1898; by E. L. Corthell.
Annual Report, Board of Regents, Smithsonian Institution, 1892.

Sargent, Chas. E., M.W.S.E., Chicago, The Testing of Inflammable Gases, January, 1907. Pam.

Warder, J. H., Sec'y W. S. E., Chicago. The Correlation and Conservation of Forces; by Grove, Helmholtz and others.

Foster, Chas. F., M.W.S.E., Chicago, 9 bound volumes.
History of Water Works, Boston, 1868.
History of Water Works, Boston, 1868-76.
Annual report, Street Laying-out Dept., Boston, 1895.
1st, 2nd and 3rd annual reports of Boston Water Board, 1876-79.
Reports, Cochituate Water Board for 1850-59. 1860-70; 1873-75.

McAlpine, A. R., Chicago, Transactions, American Society of Mechanical Engineers, Vol. 27, 1906. Paper.

New Jersey Commissioner of Public Roads, 13th annual report, 1906. Cloth.

Civil Engineers' Club of Cleveland, List of Officers and Members, 1907. Cloth.

Norwich University, Vermont. Catalogue, 1906-7. Military College. Pam.

Michigan Technic, Ann Arbor, Mich. Vol. 20, No. 1, February 1907.

New Orleans Sewerage and Water Board. 14th semi-annual report Dec. 1906. Pam.

Wilder, Geo. H., Chicago, Report of Special Telephone Commission, Chicago, April, 1907.

Mass. Board of Railroad Commissioners 38th annual report, dated January, 1907. Cloth.

Brunner, John, M.W.S.E., Chicago, Various reports of International Association for Testing Materials; Brussels Congress, 1906. Pam.

University of Illinois, Engineering Experiment Station, Urbana, Ill.
An Extension of Dewey Decimal System of Classification, by Breckenridge and Goodenough. Pam.

Huston, R. C., M.W.S.E., Hattiesburg, Miss. Report of second convention of American Public Works Association, 1906. Cloth.

Cooley, L. E., M.W.S.E., The Lakes and Gulf Waterway. A report by The Internal Improvement Commission of Illinois to Governor Chas. S. Deneen. Feb. 1907. Pam.

EXCHANGES.

American Institute of Architects, Washington, D. C. Proceedings, 39th annual convention, A. I. of A., 1905. Pam.

Geological Survey of Ohio, Edward Orton Jr. State Geologist, "Bibliography of Ohio Geology." August, 1906. Cloth.

Engineering Association of the South, Nashville, Tenn., Transactions for 1905. Pam.

Illinois State Geological Survey, Bulletin No. 3. Pam.

Engineers' Society of Western Pennsylvania, Charter and By-laws, December, 1906. Pam.

Library of Congress, Washington, D. C., Report of Librarian of Congress and Supt. of Library Bldg. and Grounds for 1906. Cloth.
"Library of Congress Publications" December, 1906. Pam.

Institution of Civil Engineers, Minutes of Proceedings, Vol. CLXVI., Part 4, 1905-6. Paper.

Junior Institution of Engineers, Journal and Record of Transactions 1905-6. Vol. XVI. Cloth

University of Montana, Missoula, Mont. "Montana Coal and Lignite Deposits," by Jesse Perry Howe. Pam.
Colorado School of Mines, Golden, Colo. Vol. 1, No. 2 Quarterly. Pam.
National Board of Fire Underwriters, Electrical Bureau, Quarterly Fire Report No. 54. Pam.
Supplement 1906 to Rules and Regulations. Pam.
Indiana Enginering Society, Proceedings, 25th annual report 1905. Pam.
American Institute of Mining Engineers, List of Members, etc., Jan. 1907. Pam.
Royal Philosophical Society of Glasgow, Proceedings 1905-6. Vol. 37. Pam.
Institution of Mechanical Engineers, London, Proceeding 1906. No. 3. Pam.
Illinois State Geological Survey, Urbana, Ill. Administrative Report for 1906, by H. Foster Bain, Director. Pam.
National Fire Protection Association, Chicago, Quarterly Bulletin, Special Hazards and Fire Record, Jan. 1907.
American Society of Mechanical Engineers, New York, Transactions 1906. Vol. 27. Pam.
American Society of Civil Engineers, New York, Transactions, December, 1906. Pam.
National Association of Cotton Manufacturers, Vol. 81, Transactions, 1906.
Association of Ry. Supts. of Bridges and Buildings, Proceedings, 16th annual convention, 1906. Paper.

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A REVIEW OF THE UNITED STATES GEOLOGICAL SURVEY FUEL TESTS UNDER STEAM BOILERS.

Prof. L. P. Breckenridge, M. W. S. E.

Presented March 20, 1907.

During the World's Fair at St. Louis, there was constructed and operated by the United States government a plant for the testing of fuels. Authority for this was granted in an Act of Congress approved February, 1904, as follows: "For analyzing and testing at the Louisiana Purchase Exposition the coals and lignites of the United States, in order to determine their fuel values and the most economic method for their utilization for different purposes, under the supervision of the Director of the United States Geological Survey, thirty thousand dollars, to be available until expended: Provided, That all testing machinery and all coal and lignites to be tested shall be contributed without charge to the Government." An additional appropriation of $30,000 was provided in April, 1904, making a total of $60,000. Since then Congress has made at each session additional appropriations for continuing these tests, as well as for tests of structural material.

During the World's Fair, the Director of the U. S. Geological Survey placed the work in charge of a committee consisting of Edward W. Parker, chairman, Joseph A. Holmes and Marius R. Campbell, to direct the construction and operations of the plant. For the last two years the plant has been operated under the supervision of Dr. Joseph A. Holmes and who still has charge of the work.

The operations of the fuel testing plant have been sub-divided as follows:

1. Field Work.
2. Chemical Investigations.
3. Steaming Tests.
4. Gas Producer Tests.
5. Coking Tests.
6. Briquetting Tests.
7. Washing Tests.

A national advisory board of thirty prominent engineers and others has been appointed by the President. To this board are submitted from time to time the plans of the several sub-divisions for discussion, criticism and approval.

The publications of the U. S. Geological Survey, relating to the work of the fuel testing plant may be obtained through a member of Congress or by direct application to the Director of the Survey at Washington. Up to the present time, three publications have been issued, but several more are in press and should soon be forthcoming.

The *steaming tests* have been made under the direction of the writer as Engineer in charge of the Boiler Division. During the World's Fair series of trials, the steaming tests were in direct charge of Mr. D. T. Randall, and since that time in charge of Mr. Walter T. Ray.

Since the beginning of these trials, about 500 steaming tests have been made. In all of these trials the same type of furnace has been used under two boilers exactly alike. The same fireman has fired by hand all of the tests. Coal has been received from all parts of the United States. It has been necessary to test these coals in turn as they reached the plant. In this way coals of widely varying nature have followed one another in our schedule. If coals of the same general characteristics could have been tested in the same group, it would have made the management of the fires more satisfactory. In some cases but one steaming test of a coal has been possible, but three tests under varying rates of combustion have been run when feasible.

The complete report of each steaming test will be found in the government reports. In the present paper it is desired to present, largely by graphical charts, a few of the results obtained, especially when classified under the several headings explained in the text.

Just how far we are justified in making comparisons of the various coals tested, the writer cannot undertake to say. Many of the coals would doubtless have given better results in another type of furnace. Still it is believed that with the large number of tests available for comparison, the curves presented must be taken to indicate rather emphatically that the truth lies in the direction suggested by the curves.

The preparation of the charts and a large part of the text of this paper have been the work of Messrs. Ray, Kreisinger, Weeks and Kuss to whom due acknowledgements are made.

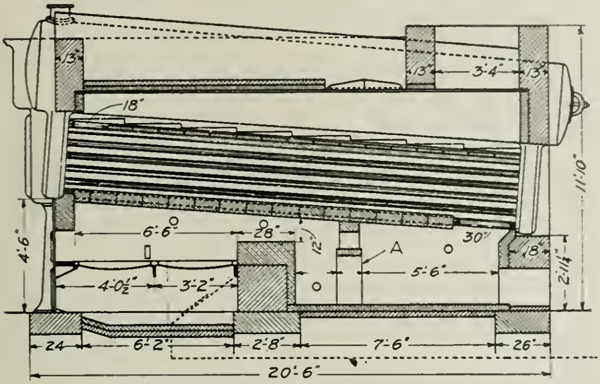
The St. Louis plant is now being dismantled and moved to the site of the Jamestown Exposition. It is supposed that a permanent location will soon be chosen for this plant and that suitable laboratories and other quarters will be provided for its work.

The work of the Boiler Division of the Fuel Testing Plant may be divided into three parts:

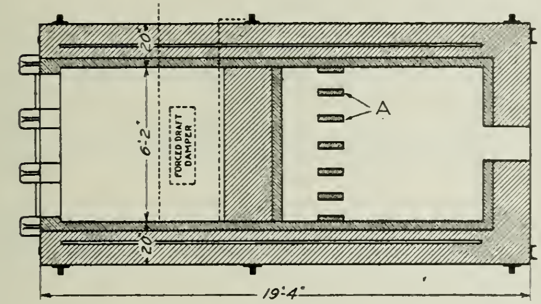
(a) Routine steaming tests made on various kinds of fuel.

(b) Analytical study of the properties of coal, the conditions under which steaming tests were run and the relation of the two to the economic results.

(c) Special investigations and deductions pertaining to the work of this division



LONGITUDINAL SECTION



PLAN

FIG. 4.

All the steaming tests were made under two standard Heine water-tube boilers, Fig. 4, equipped with hand-fired furnaces. The leading dimensions of the boilers and settings are given in the following table:

TABLE NO. 1.

Leading proportions of the two Heine water-tube boilers used in the Steaming Tests.

	Boiler No 1	Boiler No. 2
Rated capacity of boiler, horse power	210	210
Water-heating surface, square feet	2031	2031
Super heating surface...........	none	none
Furnace	Heine Standard	Fire-tile Roof
Kind of grate	Plain	McClave Rocking
Grate area, square feet	40.55	36.4
Air space through grate, per cent..	45	35
Available stack draft, inches of water	.75	.75
Height of steel stacks, feet........	115	115
Area of steel stacks, square feet...	7.67	7.67
Number of tubes, (3½ in. dia.)....	116	116
Usual steam pressure carried, pounds	80	80

The two boilers used for the steaming tests are exactly similar in construction and setting. Each is provided with its own stack and fed by its own injector.

The following definitions of the "Efficiencies," as used in this paper, will be useful:

(1) The over all efficiency E_1 of steam generating apparatus; this is the ratio of the heat absorbed by the boiler and carried away in steam, to the potential heat of the coal fired. (A. S. M. E.—code item 73.)

(2) The efficiency of furnace and boiler, E2; this is the ratio of the heat absorbed by the boiler and carried away in steam, to the potential heat of the combustible ascending from the grate. (This efficiency is identical with A. S. M. E. code item 72.)

In the government report the combustible ascending from the grate was computed in two ways:

(a) Total dry coal fired minus the ash computed from analysis of dry coal minus the combustible in the refuse.

(b) Total dry coal fired minus the total refuse of the test.

The furnace and boiler efficiency based on the combustible ascending from the grate computed by method (a) is designated as item 72*, and that based on method (b) as item 72. Method (a) is preferable.

(3) Furnace efficiency E_3, is the ratio of the heat actually developed in the furnace, to the potential heat of combustible ascending from the grate.

(4) True boiler efficiency (E_4), is the ratio of the heat absorbed by the boiler, to the heat which is available to it. The heat available for the boiler is only that portion of the heat in the furnace gases which is above the temperature of the steam in the boiler. The remaining portion of the heat in the furnace gases is below the temperature of the boiler and cannot be absorbed by it.

ROUTINE STEAMING TESTS.

(a) There have now been made in all, about 500 steaming tests on coal from all over the United States. In table No. 3 is given the number of coals tested from each state and a few average results of the tests. Most of the coals were of the bituminous or semibituminous class. These coals were burned with the combined furnace and boiler efficiency, ranging from about 60 to 70 per cent; most of them falling close to 66 per cent as seen in Chart No. 1, Curve No. 1. Several tests were made on lower grades of fuel, high in ash and moisture such as lignites, peat, Brazil coal, Argentine coal, and washery refuse. Some coals contained as much as 41 per cent of ash, and others as much as 38 per cent of moisture. When forced draft was used, these fuels gave fairly good results, both in capacity and efficiency. Thus, for instance, with a difference of pressure of about 1¼ in. of water, between the base of the stack and the ash pit, the results of tests made on two lignites, very high in moisture and a test made on washery refuse are as follows:

TABLE No. 2

TESTS OF LIGNITES AND WASHERY REFUSE.

Coal	Duration hours	Test No.	Moisture	Ash	Fixed Carbon	Volatile Matter	B.t.u. per lb. coal as fired	Capacity per cent	Item 73
Texas No. 4	7.15	298	36.30	8.19	24.90	30.61	7069	104.1	48
Arkansas No. 10	9.00	340	38.75	13.23	22.20	25.82	7750	104.0	53.76
Washery Refuse	7.18	479	10.83	41.82	30.14	17.21	7241	72.6	47,48

The results of the test on washery refuse could probably be much improved if burned in a furnace with large grate area and some mechanical arrangement for removing the ash from the fire. One advantage in burning "high moisture" fuel over "high ash" fuel, is that the moisture leaves the grate in the form of vapor and does not have to be removed mechanically as is the case with the ash. It is very likely that fuels containing very high percentages of inert matter could be burned efficiently in a properly designed furnace. This we shall admit when we consider that in foundry cupolas and blast furnaces very high temperatures are efficiently attained with a mixture of coke and ore or pig iron containing often less than 20 per cent of combustible.

TABLE No. 3

TABLE SHOWING NUMBER OF COALS TESTED FROM EACH STATE AND AVERAGES OF PRINCIPAL RESULTS.

State	Kind of Coal	No. of Tests	No. of Coals	Percentage of Builders Rated Horse Power	Equivalent Evaporation Coal as Fired at and from 212° F.	Equivalent Evaporation Dry Coal at and from 212° F.	Efficiency Code Item No. 73	Efficiency Code Item No. 72‡	B.t.u. per pound of Dry Coal	B.t.u. per pound of Combustible
Alabama	Bituminous	10	4	91.9	8.08	8.43	64.31	66.42	12656	15016
Arkansas	Bituminous	8	7	89.3	8.77	9.03	63.54	66.81	13707	15473
Arkansas	Lignite*	1	1	104.0	3.59	5.86	59.26	60.25	9549	12180
‡Brazil		2	1	79.2	5.30	5.95	57.84	61.11	9929	13731
Colorado	Bituminous	1	1	71.9	5.78	7.21	55.36	61.26	12577	13478
Florida	Peat**	1	1	113.2	5.00	6.04	57.85	58.19	10982	11003
Illinois	Bituminous	52	25	89.6	7.05	7.95	62.66	64.60	12249	14294
Iowa	Bituminous	5	5	90.7	6.24	7.13	59.55	61.83	11650	14216
Indiana	Bituminous	24	11	89.5	7.33	8.28	63.76	65.28	12549	14504
Ind. Ter.		4	4	94.9	7.73	8.19	61.69	64.04	12820	14561
Kansas	Bituminous	8	6	83.4	7.72	8.10	61.26	63.17	12780	14949
Kentucky (East)	Semi-bituminous	8	3	91.0	9.33	9.77	65.41	66.69	14417	15169
Kentucky (West)	Bituminous	5	3	88.9	7.70	8.37	62.82	64.73	12883	14547
Maryand	Semi-bituminous	1	1	80.1	8.90	9.06	63.96	65.29	13680	15681
Missouri	Bituminous	9	7	92.2	6.73	7.73	60.18	62.99	12246	14465
New Mexico	Lignitic	2	2	96.5	6.15	6.91	55.45	58.96	12021	14009
New Mexico	Bituminous	6	3	104.2	8.11	8.28	64.68	66.50	12507	14941
North Dakota	Lignite	2	1	71.3	3.79	5.93	53.29	55.34	10719	12511
Ohio	Bituminous	18	9	92.2	8.32	8.82	64.88	66.31	13130	14740
Pennsylvania	Bituminous	18	9	89.9	9.48	9.75	66.22	67.53	14218	15595
Rhode Island	Graphitic	1	1	55.8	4.81	4.93	40.91	53.11	11639	14001
Tennessee	Bituminous	24	9	102.3	8.43	8.81	64.18	65.55	13264	15093
Texas	Lignite	3	1	86.1	4.19	6.13	53.34	55.48	11102	12731
Virginia	Semi-bituminous	10	4	94.2	9.36	9.73	65.07	66.28	14436	15281
Washington	Lignitic	4	2	98.7	7.85	8.37	63.45	65.25	12725	14599
West Virginia	Bitum & Semi-Bitum	36	21	95.5	9.54	9.86	65.89	67.64	14451	15544
Wyoming	Lignite	9	5	87.7	5.75	6.65	56.85	59.85	11337	13572

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[*] Forced draft.

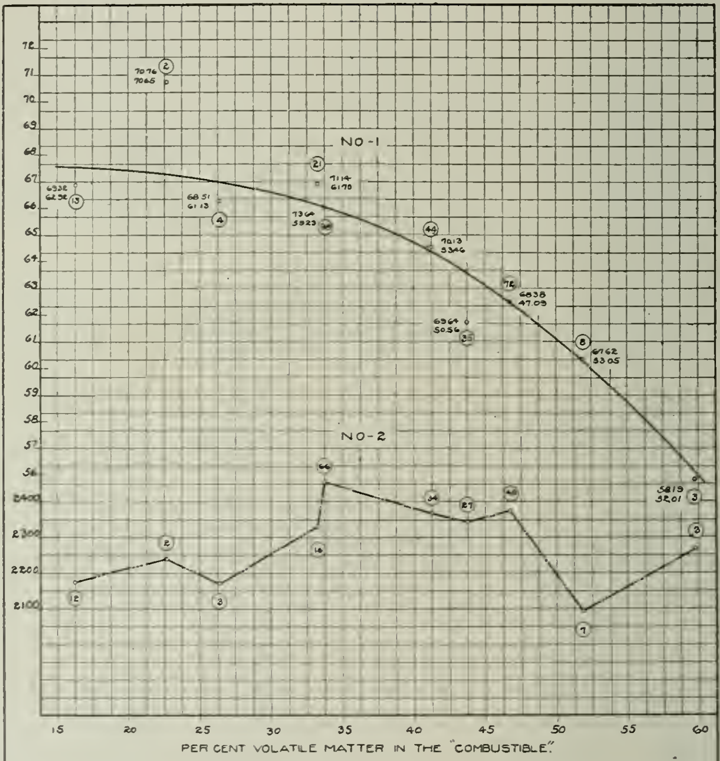
[**] Natural draft 0.8 inches of water.

[‡] This coal was in a class of its own. It was high in ash and fixed carbon, burned slowly and without smoke. Probably it was nearest to the semi-anthracite class.

ANALYTICAL STUDY OF PROPERTIES OF COAL, ETC.

(b) The coals tested under steam boilers were classified in various ways, and the economic results of the tests of the different classes were compared. Charts Nos. 1 to 8 show a few of the classifications plotted from the results of steaming tests.

In all curves of this paper, the small numbers by the points, indicate the number of tests averaged, and the four-place numbers indicate the highest and lowest efficiencies of each group.



CURVES SHOWING RELATION OF PERCENT VOLATILE MATTER IN THE "COMBUSTIBLE" TO THE FOLLOWING:

NO.-1 EFFICIENCY 72 *.

NO.-2 COMBUSTION CHAMBER TEMPERATURE – DEGREES FAHRENHEIT.

CLASSIFIED ON PERCENT VOLATILE MATTER BASIS.

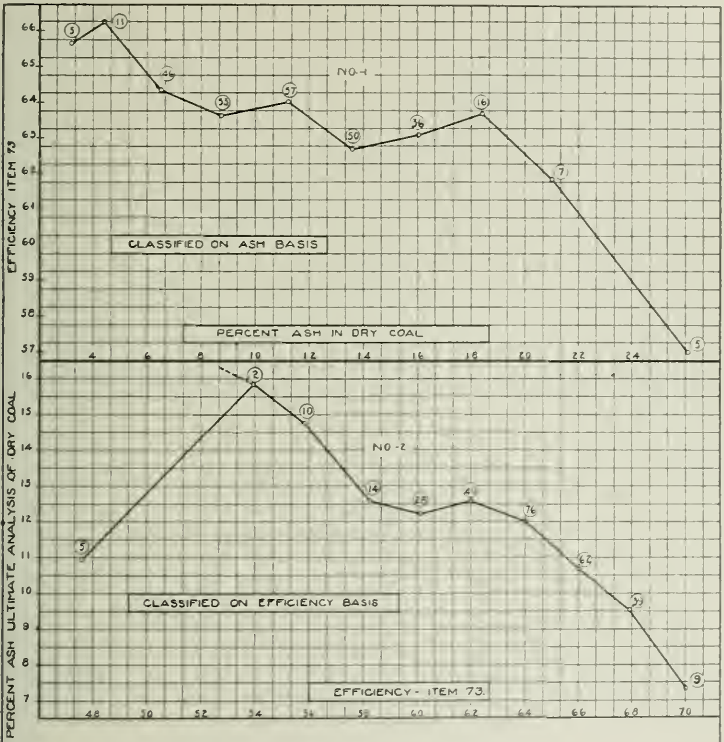
CHART NO. 1.

TESTS 101-400.

EXPLANATION OF CHARTS.

CHART No. 1 is based on about 300 tests of coals from all over the United States, classified according to the percentage of "volatile matter" in the "combustible," and considering as combustible, that portion of coal remaining after taking out the moisture and ash as determined by the proximate analysis.

Curve No. 1, is similar to many obtained by other investigators; it means that one should beware of a high percentage of "volatile matter," but not necessarily that a high "volatile matter coal" is poor, for a great deal depends on the composition of the coal, inasmuch as different coals break down very differently on heating. It has been noted, that, in general, the high "volatile matter" coals, have some other undesirable features, such as high ash content. The most important thing to emphasize is, that even with an apparatus having a good furnace, the high "volatile matter" coals are at a slight disadvantage.

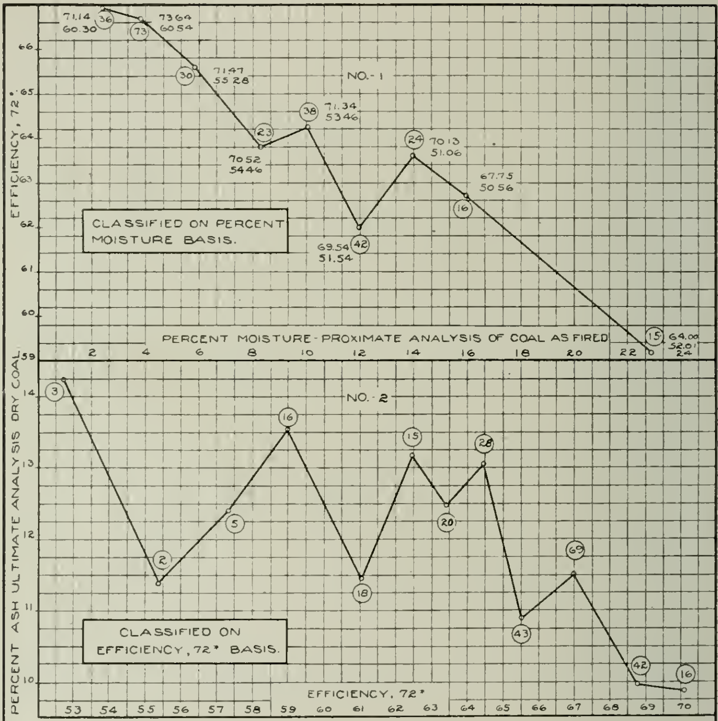


CURVES NO-1 AND NO-2 SHOWING RELATION BETWEEN:
PERCENT OF ASH FROM ULTIMATE ANALYSIS OF DRY COAL AND EFFICIENCY ITEM 73. CLASSIFIED ON TWO DIFFERENT BASES.

CHART NO 2.
TESTS 120-410.

Curve No. 2, shows that the combustion chamber temperature rises with the "volatile matter" of the coal, up to about 38 per cent and then drops. The rise of the temperature is due to the fact that the "volatile matter" of the coal is driven off the fuel bed and burns in the combustion chamber, so that the temperature of the gases of combustion is measured before the heat is dissipated from them. The rise is also due to the increased rate of combustion; for as the "volatile matter" increases, the coal burns more rapidly, and less air is used to burn one pound of combustible.

Beyond 38 per cent of "volatile matter," the coals become high in ash and moisture, in fact all the lignites are classed among the coals at the right hand end. Both the ash and the moisture, reduce the combustion chamber temperature. The high ash causes a slower rate of combustion and consequently more air is used per pound of "combustible." The moisture lowers the temperature directly by its high specific and latent heat. Work on the constitution of the cellulose derivatives of coals now being done at this Plant, and at several other places, should give some valuable information on



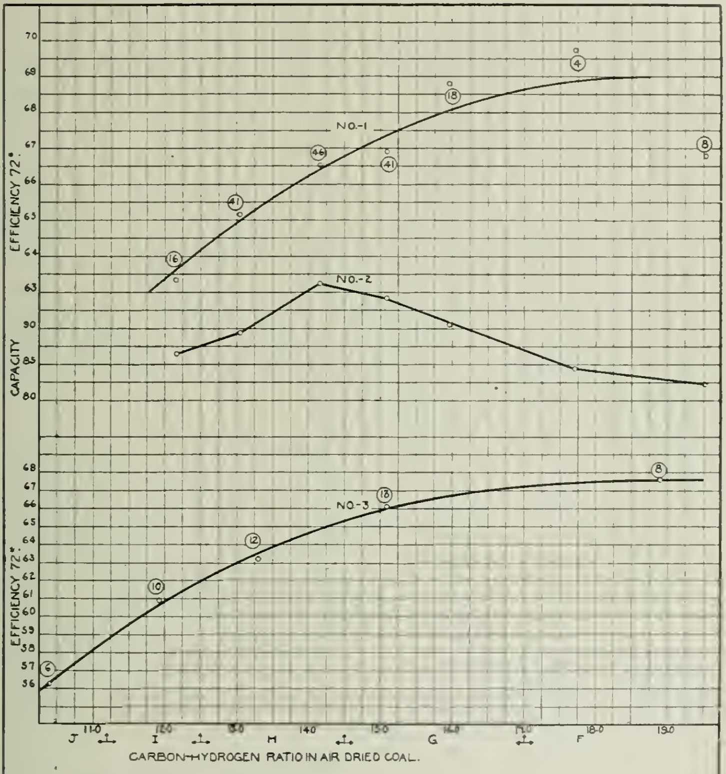
NO.-1 CURVE SHOWING RELATION OF PERCENT MOISTURE, PROXIMATE ANALYSIS OF COAL, TO EFFICIENCY, 72.° TESTS 101-400.

NO-2 CURVE SHOWING RELATION OF EFFICIENCY, 72° TO PERCENT ASH ULTIMATE ANALYSIS OF DRY COAL. TESTS 120-400.

CHART NO. 3

such practical questions as these. The customary "proximate analysis" is only an empirical method and can be expected to give nothing more than clues; much more is to be expected from ultimate analysis.

Chart No. 2 is based on 286 reliable tests, classified according to each of the two items, "Percent of Ash in Ultimate Analysis of Dry Coal"; and, "Over-All Efficiency, Code Item 73," which item is the ratio of the heat put into the water, to the potential heat in the coal, put onto the grate. Referring to the upper curve it is noticeable that the ash affects the efficiency by only two or three per cent until the ash content, rises above twenty per cent, when the efficiency falls rapidly; there are, however, not so many tests in the last two points as in the others.



NO.1 = EFFICIENCY, 72°. TESTS 120-401.
NO.2 = PERCENT OF RATED CAPACITY DEVELOPED.
NO.3 = EFFICIENCY, 72°. TESTS 1-78.
TESTS 1-78 WERE ALL MADE AT ABOUT CAPACITY.
THE ABOVE OMITS WASHED, DRIED, AND BRIQUETTED COAL TESTS.
RATIO TAKEN FROM ULTIMATE ANALYSIS OF AIR DRIED CAR SAMPLES.

CHART NO. 4.
CLASSIFICATION OF COAL.
GENERAL CURVES.

The lower curve shows the same fact inversely, that is, the high efficiency tests are on coals low in ash; it indicates that an ash increase of one per cent causes a drop of about one-half per cent in efficiency for each per cent of ash, or, only one-fourth as much as in the upper curve. The average then, is about one per cent decrease in efficiency for one per cent increase in ash. The five points on the left end of the lower curve represent tests on low ash lignites, and therefore, are really not comparable with the others.

The two curves show that ash is undesirable; but even so the commercial choice of coals, so far as ash is concerned, is more a question of price, freight rates, labor costs and storage capacity.

Chart No. 3, contains two separate curves, each based on the same tests, and is self-explanatory. The upper curve is somewhat misleading because the poorer coals contained on the average more free moisture. Just what effect different percentages of free moisture would have in the case of the same coal, reckoning above dry coal, is still undetermined. This is a line of investigation that will be taken up in the future. This curve merely indicates that coals high in free moisture should be suspected and watched, especially when burning them in furnaces of this particular type.

The great variability of the lower curve suggests that ordinary percentages of ash have little effect on efficiency, and that the best efficiencies are obtained only with low ash. No doubt other apparatus is available which would give better results on dirty coal, than have been obtained by hand firing on a plain grate.

Chart No. 4, is based on the classification of coal according to carbon hydrogen ratio in air-dried coal. (Coal is air-dried in the laboratory before analysis merely to facilitate accuracy. It really has no scientific or practical significance.) One hundred and seventy-four tests were employed for this purpose on about seventy-five different coals. Washed, dried and briquetted coals were rejected. It was not expected that this classification would be of as much service as one based on the same ratio in either coal as received or in dry coal, since the amount of drying to which a sample is subjected is dependent upon the conditions, which vary from day to day. The statement just made seems to be borne out by the fact that the average points from which Curve No. 1 (the general efficiency curve) is derived, fall farther from such a curve than is the case in the general curves derived from the ratio of carbon to hydrogen using either coal as received or dry coal.

The ratio of carbon to hydrogen should have been obtained from the ultimate analysis of the boiler test sample after air drying, but this data was not available. The ratio used is really calculated on the air dried coal of the car sample. This might account for some of the variations of some of the points from the curve.

Curve No. 2. A broken line joining average per cent rating for all tests coming in each group is shown on the chart.

Curve No. 3 shows the relations between carbon-hydrogen ratios on air dried coal and efficiency for boiler tests conducted during

1904 by the U. S. Geological Survey. The tests in which washed and briquetted coals were burned are omitted.

It was decided to abandon this classification and to use the ratio of carbon to hydrogen of coal as received and of dry coal.

The curves and conclusions on classifications, based on carbon-hydrogen ratios of coal as received and of dry coal, were derived from approximately two hundred and fifty (250) boiler tests run in one series. The tests included raw, washed, briquetted and a few mixed coals.

The relative values of the classifications were based on the uniformity of the general efficiency curves, efficiency here meaning the efficiency of the boiler on the combustible basis, (the combustible consumed as shown by approximate analysis less the combustible

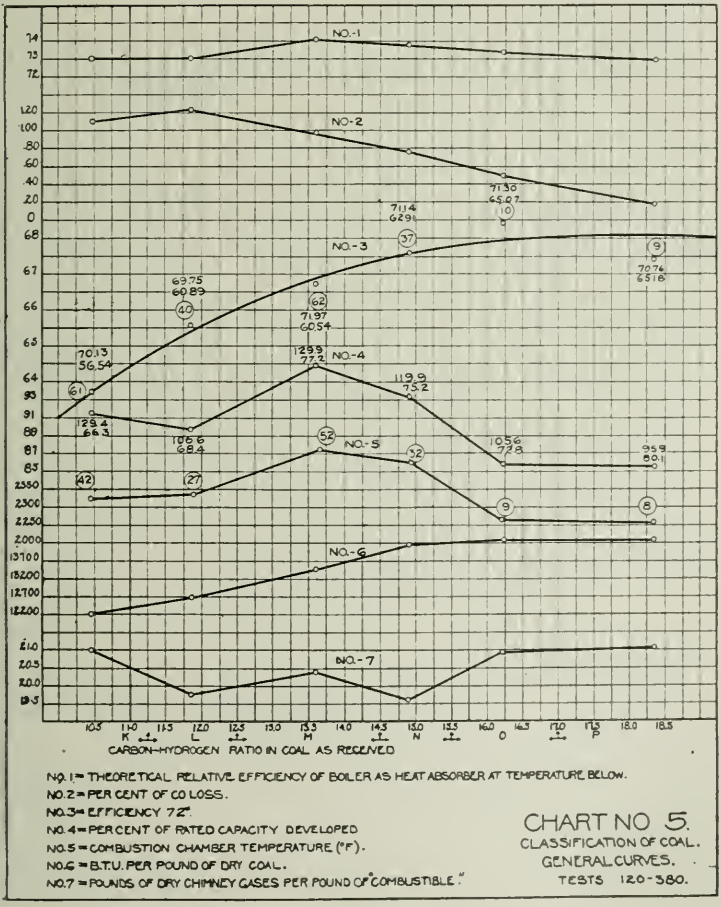


CHART NO 5.
CLASSIFICATION OF COAL.
GENERAL CURVES.
TESTS 120-380.

lost in refuse as determined by its analysis). The item used for the efficiency is 72*, defined above.

CLASSIFICATION BY RATIO OF CARBON TO HYDROGEN OF ULTIMATE ANALYSIS OF COAL AS RECEIVED.

CHART NO. 5. Here the carbon-hydrogen ratios were computed from the ultimate analyses made by the "Chemical Division" on boiler test samples.

These ratios were divided into six groups, as follows:

Group K, including all values up to 11.2.
Group L, from 11.2 to 12.5.
Group M, from 12.5 to 14.5.
Group N, from 14.5 to 15.5
Group O, from 15.5 to 17.0.
Group P, all values over 17.0.

The several items in each group were then averaged and curves plotted on the following: Efficiency (72*); per cent CO loss; combustion chamber temperature (by Wanner Optical Pyrometer); per cent of rated capacity of boiler developed; pounds of dry chimney gases per pound of "combustible" (coal free from ash and mositure); B. t. u. per pound of dry coal.

A comparison of the averages just mentioned shows that no one item was maintained constant or even approximately so, so that whatever conclusions may be made thereon must necessarily be considered anything but absolute.

Particular mention had best be made concerning the per cent of rated capacity attained in the trials which if maintained constant might have aided materially in defining more closely the relative causes and effects as indicated by the other items, although it is believed that these items are as much dependent upon the kind of coal as upon the per cent of rated capacity attained.

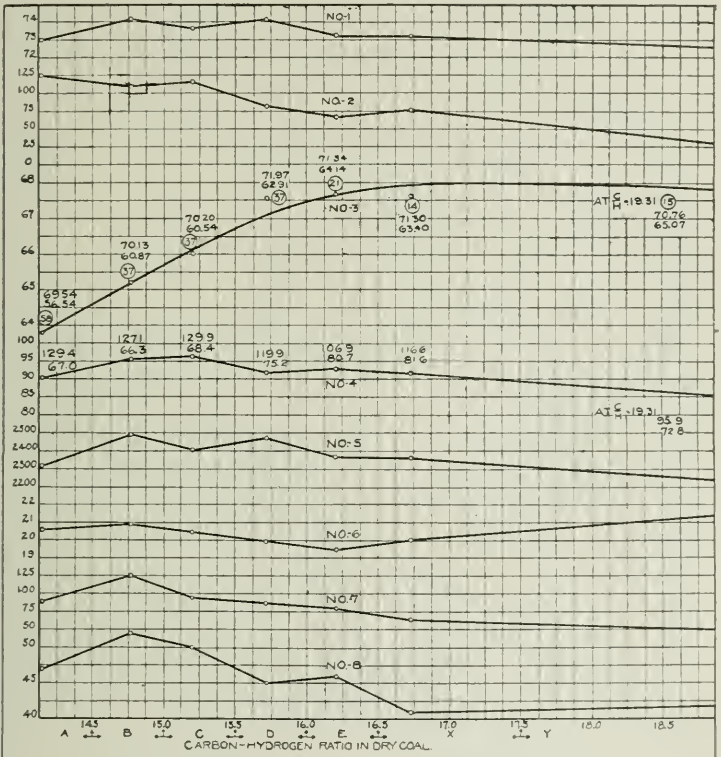
The curve drawn along the average efficiency points on the chart is so uniform that the conclusion might easily be reached that a classification such as the ratio of carbon to hydrogen is of much value. On selecting an individual group there is no such close agreement, as is shown by the range of efficiencies noted at each point of the general efficiency curve. The general curve shows a gradual increase of efficiency as the ratio of carbon to hydrogen increases, becoming horizontal for the high ratios.

A comparison of the highest efficiencies of the groups shows a marked uniformity. The range of efficiencies in each group (not shown on the chart) decreases as the ratio of carbon to hydrogen increases, thus seeming to indicate that efficient burning of coals of a lower carbon to hydrogen ratio, is a matter of much greater uncertainty than when the ratio is high.

The curve of per cent CO loss, indicates maximum incomplete combustion in the low ratio groups, decreasing to nearly zero in the high ratio groups. This is in accord with the statement made regarding the uncertainty of burning coals of a low carbon-hydrogen ratio.

The B. t. u. *curve, No. 6,* rises as the carbon-hydrogen ratio increases.

A broken line connecting the averages of the per cent or rated capacity of each group, is shown by *Curve No. 4.* This line points out a wide variation in capacity attained. The figures given with each point on the general curve, show a much wider range of the same item as between the different trials of each group, than between groups. The variation of per cent rating tended to remove the average efficiency from a uniform efficiency curve; the average efficiency increased, in general, as the average per cent of rating decreased.



NO. 1 = THEORETICAL EFFICIENCY OF BOILER AS HEAT ABSORBER AT TEMPERATURE BELOW.
NO. 2 = PER CENT OF CO LOSS.
NO. 3 = EFFICIENCY, 72°.
NO. 4 = PER CENT OF RATED CAPACITY DEVELOPED.
NO. 5 = COMBUSTION CHAMBER TEMPERATURE (°F).
NO. 6 = POUNDS OF DRY CHIMNEY GASES PER POUND OF COMBUSTIBLE.
NO. 7 = AVERAGE DIAMETER OF COAL.
NO. 8 = PER CENT OF CLINKER IN REFUSE.

CHART NO. 6.
CLASSIFICATION OF COAL.
GENERAL CURVES
TESTS 120-380.

From the combustion chamber temperature points, we obtain a broken line which is nearly parallel to the per cent of rated capacity line. The highest temperatures were obtained in the middle groups, the lowest temperature in the highest groups.

It is difficult to arrive at a conclusion from the line representing the number of pounds of dry chimney gases per pound of "combustible."

Chart No. 6. Here the classification has been made by using the ratio of carbon to total hydrogen as determined by the ultimate analysis of dry coal. By this method we eliminate that portion of the hydrogen that appears in the moisture determined by the official proximate analysis, and there should consequently result a more nearly constant carbon-hydrogen ratio for any given coal.

The ratios were divided into seven different groups as follows:

Group A, including all values up to 14.5.
Group B, from 14.5 to 15.0.
Group C, from 15.0 to 15.5.
Group D, from 15.5 to 16.0.
Group E, from 16.0 to 16.5.
Group X, from 16.5 to 17.5.
Group Y, all values over 17.5.

As in the previous classification, all the values in each group were averaged and each average plotted with its corresponding average of carbon-hydrogen ratio.

There is no particular difference in the general curves as derived from the two classifications, based on dry coal and coal as received. To this general chart, two more curves have been added, that is a curve of average diameter of coal and one of per cent of clinker in the refuse.

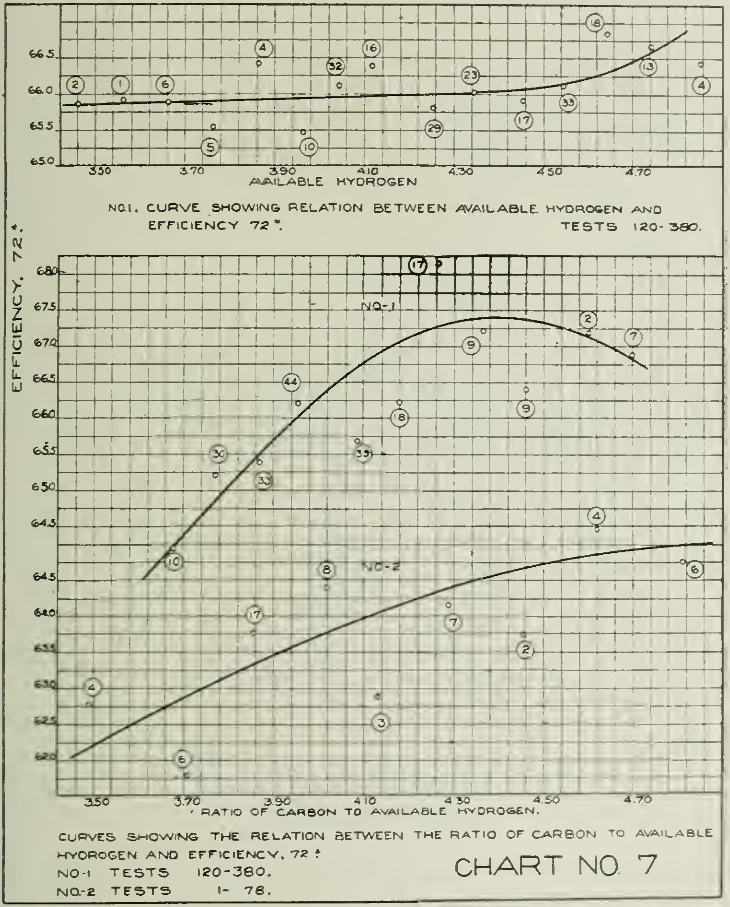
The curve No. 7, of average diameter of coal as fired, shows that for the higher ratios of carbon to hydrogen there is a gradual reduction in average diameter. Nearly all of the coals used in the tests passed through the same crusher. It is not to be assumed that the ratio of carbon to hydrogen influences the ease with which the coal breaks for this can be accounted for in other ways. The coals of low carbon-hydrogen ratio contain the highest per cent of clinker in refuse, which is accidental.

Curve No. 1. Theoretical Efficiency of Boiler as a Heat Absorber at Temperature Below, is relative only and is probably as a whole either too high or too low, and the various points of it may be high or low relative to each other, but it serves its general purpose,—to show less complete combustion of the coals low in carbon-hydrogen ratio; the distance between this curve and the "72" efficiency curve, is greater, the lower the carbon-hydrogen ratio.

Chart No. 7 gives a classification of efficiency (72*) on a ratio of carbon to available hydrogen as a basis. As the ratio of carbon to available hydrogen increases, there is a considerable increase in efficiency (72); however, the curve is very irregular.

Curve No. 1 and *No. 2* are similar but on two different series of tests.

Curve No. 3 is a classification of efficiency (72) on available hydrogen as a basis. The efficiency varies but little over the entire range of available hydrogen.



NO. 1. CURVE SHOWING RELATION BETWEEN AVAILABLE HYDROGEN AND EFFICIENCY 72*. TESTS 120-380.

CURVES SHOWING THE RELATION BETWEEN THE RATIO OF CARBON TO AVAILABLE HYDROGEN AND EFFICIENCY, 72*.
NO-1 TESTS 120-380.
NO-2 TESTS 1- 78.

CHART NO. 7

EFFECT OF SIZE OF COAL.

Preliminary to the section devoted to the results obtained by using coal of different sizes, it is necessary to state how the coal is received at the United States Coal-Testing Plant and how the size is determined and to suggest how more might be done with size of coal.

Nearly all of the coal tested, was passed through a crusher; consequently coals of widely varying characteristics were reduced to the same size. Therefore, by classifying coals on a *size basis,* as was done, we have, for instance, averaged a good eastern coal, with a poor-grade western coal. While on the average, *size* shows some few general relations, it would seem that the best comparable data could be obtained, by taking one coal, say mine run, and, after separating the various sizes, making a series of tests on each size. Even in this way one would not be testing the same grade of coal since the smaller sizes are sure to be higher in ash, but nevertheless this is the commercial side of the problem.

Determining Average Diameter.—A part of the sample of the coal tested is passed through a revolving screen perforated its entire length with round holes varying in size from ⅛-in. to 1-in. in diameter. These holes are arranged in strips of varying width, the width decreasing as the size of hole increases. The coal passing through each hole is weighed separately and the data from boiler room as reported, is shown in Table 4.

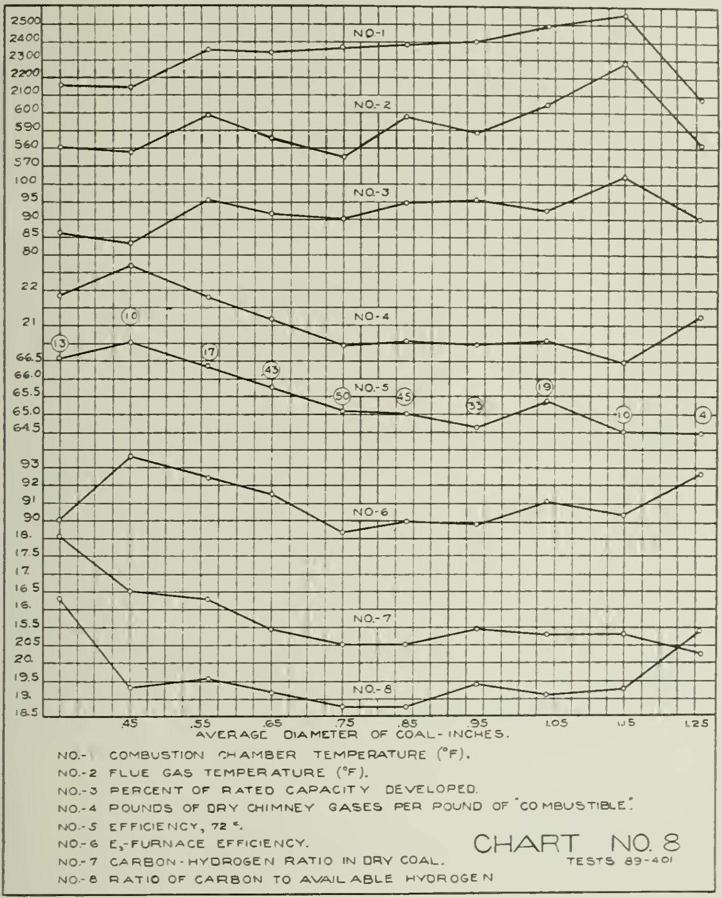
TABLE NO. 4.

SIZING TEST OF COAL.

Diameter of Hole. (Inches)	Pounds of Coal Thru Each Set of Holes.	Pounds of Coal Thru Each Set of Holes Reduced to 1.00 Pounds	Weight of Coal Determining Average Diameter.
1	2	3	4
⅛	20	20.4	2.6
¼	14	14.3	3.6
⅜	18	18.4	6.9
½	12	12.2	6.1
¾	27	27.6	20.7
1	4	4.1	4.1
1½	3	3.0	4.5
	98 lb.	100.0	$\frac{48.5}{100.0} = .49$

Column No. 2 shows that 98 lb. of coal was sized. No attempt is ever made to weigh out exactly 100 lb. so the weights must be reduced to 100 as has been done in Column No. 3. We now have the percentages of the various sizes of coal. In an average diameter each of the above percentages has a certain weight, this being determined by the diameter it represents. In getting average diameter then. Column No. 3 is multiplied by Column No. 1 and the sum of this column of products, divided by 100, gives the average diameter. Column No. 4 is divided by 100 which is the same as writing No. 3 in per cent.

CHART No. 8, was made on the coals tested from Test 89, to Test 401, and shows that as the average diameter increased from 0.33 to 1.26-in. the capacity increased about 15 per cent; the highest efficiency (72*) values were obtained with the smallest sizes; there was practically no change in the efficiency of the furnace; there was a slight decrease in the pounds of dry chimney gases per pound of combustible; the carbon-hydrogen ratio figured from the dry coal decreased considerably, showing that the good coals fall in the groups of smallest average diameter, this being probably due to the fact that some of the good coals broke up badly in transportation and in passing through the crusher; the combustion chamber temperature increased about 400 Deg. Fahr.

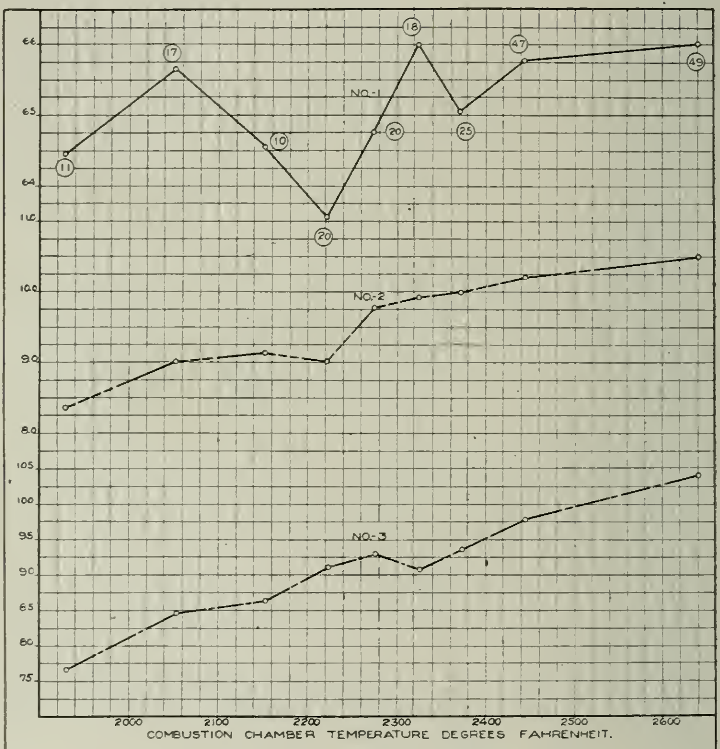


This is so different from the usual conclusion that it should be borne in mind that it is only tentative, because other conditions varied so widely. The study of effect of size as above outlined is not specialized enough, for undoubtedly other factors than average size are influential, perhaps percentage of voids, as dependent on percentage of various sizes forming average diameter, shape of pieces, etc.

In discussing the effect of average size of coal as based on these tests it is well to remember that none of the coal is really fine, for the lowest average sizes are about 0.3 of an inch; the same applies to the other end, for the largest sizes averaged only 1.25 inches.

FURNACE TEMPERATURES.

Statements are often made that high furnace temperatures are accompanied by high over-all efficiency and that the highest possible furnace temperature should always be striven for to obtain the best fuel economy. To test these statements, the boiler trials made at the Coal-Testing Plant were grouped into classes according to the temperature in the rear of the combustion chamber and the averages for the corresponding results of the trials were obtained.



CURVES SHOWING RELATION BETWEEN COMBUSTION CHAMBER TEMPERATURE AND THE FOLLOWING:
NO. 1 EFFICIENCY, 72 %.
NO 2 CO_2 IN FLUE GASES, SAMPLES TAKEN IN HOOD.
NO. 3 PERCENT RATED CAPACITY OF BOILER DEVELOPED.
CLASSIFIED ON COMBUSTION CHAMBER TEMPERATURE AS BASIS.

CHART NO. 9.
TESTS 150-400.

The temperatures in the rear of the combustion chamber were taken with a "Wanner Optical Pyrometer," through a two inch opening in the side wall. This opening was about eight inches in front of the gas passage from the combustion chamber into the tube chamber. For most of the tests, readings were taken every ten minutes; for others the readings were taken every twenty minutes. The pyrometer was standardized every morning when the test was started.

Chart No. 9, is a classification of 217 tests on many coals from all over the country, based on temperature in the rear of the combustion chamber. In general, the poorer coals fall on the left part of the sheet. The most interesting showing is that the "boiler-efficiency," (72*), rises only 2 per cent as the combustion chamber temperature rises from 1800 to 2700 Deg. Fahr. This is in accordance with other charts and the theory of boilers, given elsewhere in this paper, to the effect that a rise of about 1000 Deg. Fahr. in furnace temperature, improves the boiler efficiency as a heat absorber only about 10 per cent, most of which gain is lost owing to the restricted oxygen supply required to get the high temperatures.

Curve No. 2, shows a slight but persistent rise of CO_2 content in flue gases with increasing furnace temperatures, as is reasonable; it ought to be more marked; but air infiltration through the settings reduced the CO_2 percentage somewhat.

Curve No. 3, shows a decided increase in amount of steam made as the temperature rises. Since capacity is the rate of absorption of heat by the boiler, the capacity must necessarily increase with rise of combustion-chamber temperature.

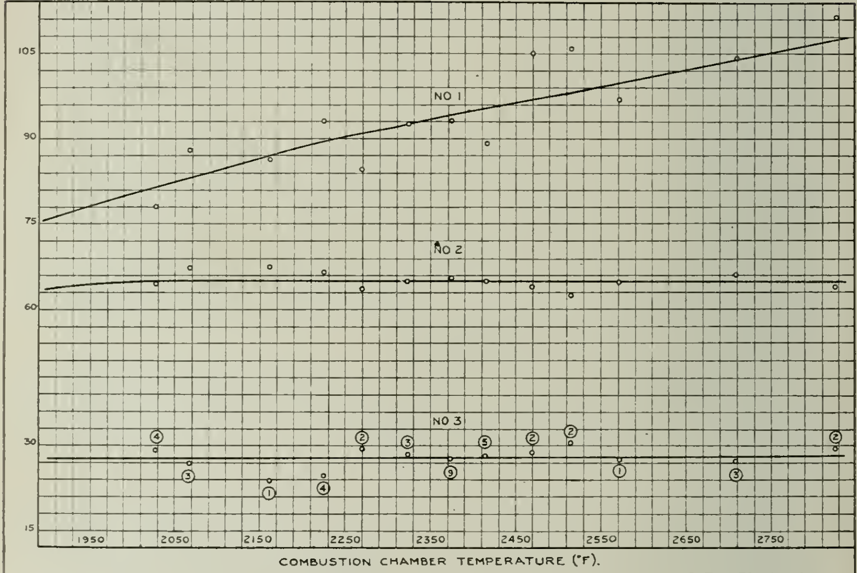
On examining the coals of the tests plotted in Chart No. 9, it was found that some of the eastern semi-bituminous, short-flaming coals were averaged with the western coals and this raised the efficiency of the groups on the left hand of the curve in Chart No. 9.

Chart No. 10 was compiled to find whether the small variation in efficiency above referred to was due to the fact that different classes of coals were used in the compilation of Chart. No. 9. In Chart No. 10 only coals from the Illinois coal basin were used. The striking showing of this chart is that the "Boiler Efficiency" (72*) is practically constant throughout the whole range of furnace temperature. If anything, the tests with the temperatures from 2050 to 2350 Deg. Fahr. have the highest efficiency. All these coals are inclined to evolve compounds difficult to burn, and thus it is that the lower the percentage of oxygen present and the higher the temperature above any reasonable ignition point, the less complete is the combustion.

With these coals, the decreasing efficiency of combustion in our apparatus seems to off-set the increasing efficiency of the boiler as a heat absorber, which is only about 10 per cent or 12 per cent within the range 1850 to 2850 Deg. Fahr, judging from the work given elsewhere.

In this chart, as in all others where capacity is shown as a function of temperature, the two rise together. This is clear on remember-ing that much heat is absorbed through the tile roof of the furnace, and the greater the amount of coal burned, the less in percentage will this absorption amount to, so that the temperature at the last point of combustion is higher. There are also minor reasons, mostly based on this same fundamental cause.

In the same chart Curve No. 3 shows the interesting feature that the sum of the loss up the stack, plus the unaccounted for in the heat balance, is very nearly constant for all temperatures, although to get high combustion chamber temperature, less air is used for combustion and the loss up the stack is reduced; the unaccounted for rise makes up for what is saved on waste gases.



CURVES SHOWING RELATION BETWEEN COMBUSTION CHAMBER TEMPERATURE AND THE FOLLOWING
NO·1 PERCENT RATED CAPACITY DEVELOPED.
NO·2 EFFICIENCY . 72•
NO·3 PERCENT UNACCOUNTED FOR PLUS PERCENT LOSS UP STACK
CLASSIFIED ON COMBUSTION CHAMBER TEMPERATURE (°F)
USING ILLINOIS AND INDIANA COALS.

CHART NO 10.
TESTS 125-385.

The objection will probably be made that in the efficiency curves of Charts Nos. 9 and 10, no attention was paid to the capacity, and that tests with high combustion chamber temperatures were run at high capacity which reduced the efficiency. To remove this objection the tests of Chart No. 9 were classified into capacity groups; each of these capacity groups was then sub-divided into smaller groups according to combustion chamber temperature and the average efficiencies for these groups were then obtaind. Table No. 5 shows the relation of the combustion chamber temperature and the efficiency of each capacity group.

No attempt is made here to discuss in detail the causes of the showing of this table. It indicates that for every capacity group the "boiler-efficiency" (72*) is independent of the combustion-chamber temperature, and practically constant throughout the whole range of temperature. The suggested explanation is, that as the temperature of combustion rises, the oxygen content of the gases decreases, which reduces the completeness of combustion sufficiently to nearly neutralize the slight rise of boiler efficiency, due to higher initial temperatures. This same result is shown for all tests grouped with regard to amount of coal burned, in Charts Nos. 9 and 10. This table is one of the most significant in this paper.

TABLE NO. 5

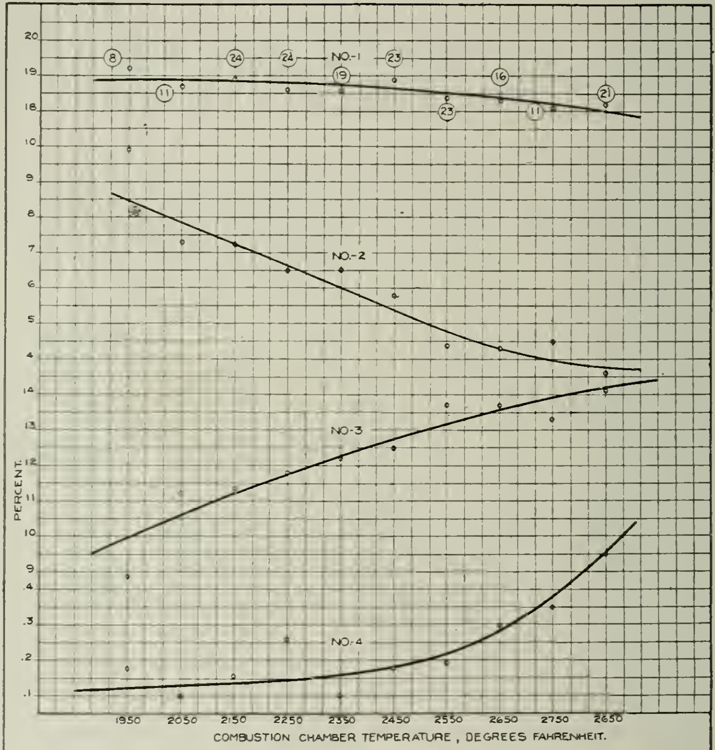
RELATION BETWEEN COMBUSTION CHAMBER TEMPERATURE AND EFFICIENCY ON TESTS RUN AT SAME CAPACITY.

PER CENT RATED CAPACITY DEVELOPED.

70 to 75			75 to 80			80 to 85			85 to 90		
Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*
1870	1	66.38	1880	1	60.89	1961	1	67.64	2067	6	65.93
1936	2	64.07	1967	2	59.79	2046	4	62.33	2140	2	64.56
2253	1	65.04	2039	3	66.35	2163	3	67.68	2231	9	66.13
....	..	.....	2118	1	65.95	2259	11	65.79	2354	8	64.83
....	..	.....	2247	1	68.54	2325	5	67.39	2421	5	65.79
....	..	.....	2350	2	63.68	2419	5	66.87	2525	1	65.25
....	..	.....	....	..	.....	2597	1	66.82	2672	2	65.94
Average Efficiency 72* for Each Group.											
		64.89			64.12			66.06			65.59

90 to 95			95 to 100			100 to 105			105 to 110		
Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*	Combustion Chamber Temperature °F.	Number of Tests	Efficiency 72*
2050	2	67.46	2248	6	67.32	2256	2	65.09	2290	3	66.19
2178	2	65.88	2368	7	65.63	2327	3	66.46	2345	3	67.44
2244	3	69.23	2457	11	65.83	2474	4	67.55	2448	9	65.03
2359	12	65.45	2554	6	64.88	2550	5	66.10	2534	1	65.83
2456	8	65.88	2627	2	65.80	2660	1	65.22	2653	5	65.01
2546	5	69.41	2722	1	68.06	2839	2	66.55	2708	1	64.61
2637	1	68.61	....	..	.....	....	..	.....	2864	1	73.64
2708	1	64.97	....	..	.....	....	..	.....	....	..	.....
Average Efficiency 72* for Each Group.											
		66.60			65.95			66.38			66.81

CHARTS NOS. 11 AND 12, and the upper curve in CHART 13 support the suggested explanation made in the last paragraph, that the lack of rise of the boiler and furnace efficiency with the rise of combustion chamber temperature, is due to incompleteness of combustion. Chart No. 11 shows that as the combustion chamber temperature rises, the per cent of CO2 in the flue gases does not increase in proportion with the temperature and that the per cent of CO rises. This rise of CO increases rapidly after the temperature reaches 2400 Deg. Fahr.



RELATION OF GAS COMPOSITION IN REAR COMBUSTION CHAMBER TO TEMPERATURE AT SAME PLACE.
SAMPLES OF GAS TAKEN THRU WATER JACKETED IRON PIPE.
CURVES OBTAINED BY CLASSIFYING ON COMBUSTION CHAMBER TEMPERATURE BASIS.
CURVE NO.-1 = $CO_2 + O_2 + CO$ CURVE NO.-3 = CO_2
CURVE NO.-2 = O_2 CURVE NO.-4 = CO

CHART NO. 11

TESTS 318-382

The upper curve of Chart No. 13 indicates that in general high unaccounted for is accompanied by high CO loss, which in turn is only an indication of incomplete combustion. It can be reasonably expected that when CO occurs, the flue gases contain other combustible gases, which although they may be in immeasureable quantities, may account for a heat loss even double that indicated by CO.

The lower curve of the same Chart shows that high efficiencies were obtained with a low CO in the flue gases, while the low efficiencies are accompanied by high CO.

It stands to reason to attribute part of the unaccounted for to the escape of unburned hydrocarbon gases and smoke, and that the unaccounted for increase, is due to the increased hydrocarbon losses.

The percentage of the radiation loss is nearly the same for the same capacity and rather smaller in percentage as the capacity increases. It was assumed that the radition loss at 80 per cent of rated capacity, was 5 per cent, and at 130 per cent rated capacity is 3.45 per cent. The radiation losses for other capacities were found from a straight line joining these two points. The above assumption was arrived at by considering that 2-5 of the radiation occurs from the boiler proper and is constant in quantity of heat for constant pressure, and 3-5 of the radiation is from the furnace walls and front; this latter portion of the radiation varies with the temperature of the furnace and may be taken to vary with capacity. Thus the constant radiation from the boiler proper makes the total radiation less in *percentage* for high capacities than for low capacities.

The radiation from the boiler proper was determined by a series of radiation tests made on boiler No. 1. The uptake of the boiler was closed by boards and these were covered with a layer of asbestos cement to prevent the escape of heat. The furnace and ash pit doors were bricked up so that cold air could not enter the setting. The boiler was emptied of water and live steam from another boiler was run into it. After the boiler and the air inside of the setting had been thoroughly heated, the steam condensed for two hours was weighed, this condensation being a measure of the constant heat radiation from the boiler proper.

Table No. 6, gives the results of six radiation tests.

TABLE NO. 6

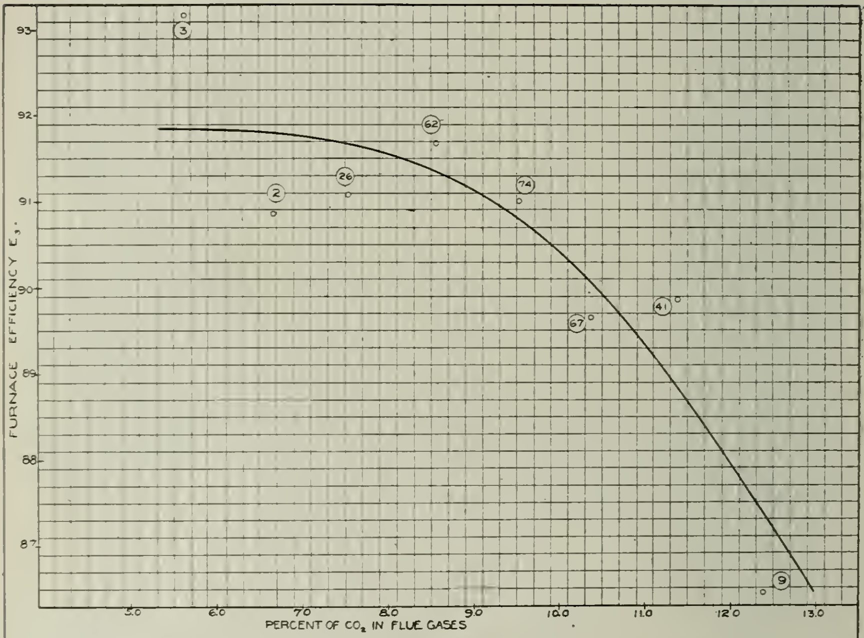
RESULTS OF RADIATION TESTS.

Test No.	Steam Pressure lb. by gage	Steam Condensed per hour, lbs.	B. t. u. radiated per hour	Steam Temperature deg. Fahr.	Boiler room temperature deg. Fahr
I	76.7	201	178,600	321	90
II	76.5	191.1	169,900	321	..
III	82.5	196.2	173,600	325.4	92
IV	80.0	217	192,800	323.5	92
V	77.0	211.8	188,300	321.4	90
VI	76.0	199.4	177,200	321	90
Total	468.7	1,216.5	1,080,400	1,933.3	454
Average	78.11	202.7	180,070	322.2	90.5

The above method of determining radiation is perhaps crude, nevertheless it will help in obtaining relative results.

Having the radiation loss determined, the incomplete combustion is equal to the unaccounted for item minus the radiation loss and plus the CO loss. The furnace efficiency is equal to or proportioned to 100 minus incomplete combustion. The above is the general principle by which the furnace efficiencies used in CHART No. 12 were obtained.

CHART No. 12 shows that as the CO_2 content in the flue gases increases, the efficiency of the furnace drops, and this drop is very rapid after the amount of CO_2 in the flue gases reaches a certain limit. This is contradictory to the statements sometimes made that high furnace temperatures are accompanied by high furnace efficiencies. To obtain high temperature, the air supply must be reduced, and this reduction of air necessarily increases the incompleteness of combustion, as shown by Chart. No. 11.

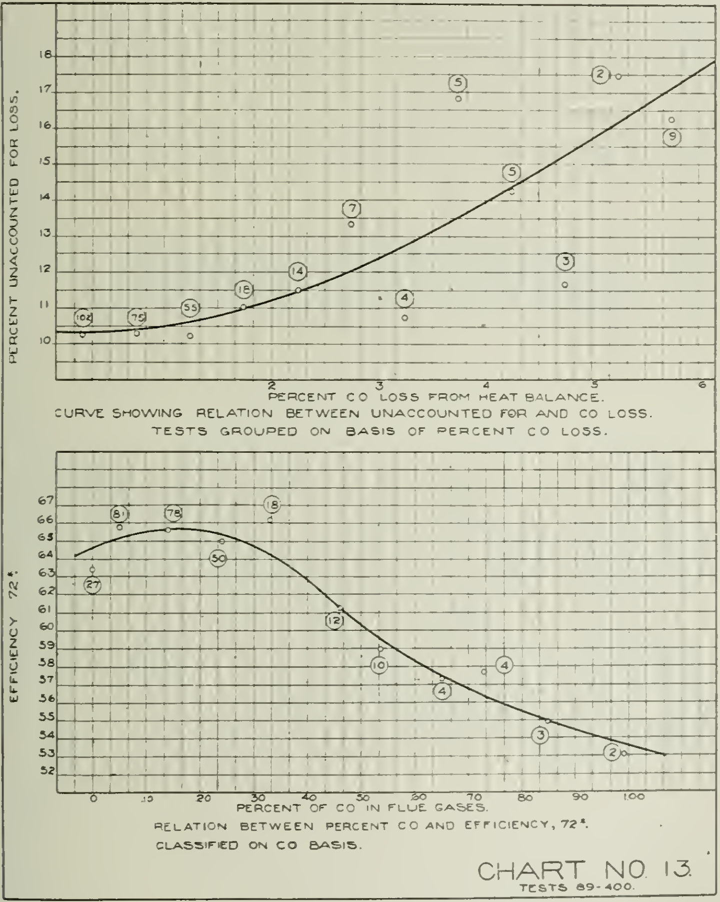


RELATION BETWEEN PERCENT OF CO_2 IN FLUE GASES AND FURNACE EFFICIENCY (E_3).
CLASSIFIED ON CO_2 BASIS. TESTS 89-401. CHART NO. 12.

CHART No. 14 gives Variation of Temperature in Heine Furnace with Firing, as observed with Wanner Optical Pyrometer. In this chart are shown the variations of the temperatures in the fuel bed, over the fire, and in the combustion chamber, with two very different coals. These temperatures were taken with the Wanner Optical Pyromter, which was standardized before and after each series of observations. Every series of readings was taken without disconnecting the pyrometer from the battery after the standardization. Owing to the fact that only one pyrometer was available, the temperatures were not taken simultaneously.

The chart shows clearly the following three things:

(1) During and shortly after each firing the temperature over the fire and to some extent the temperature in the fuel bed drops and the temperature in the combustion chamber rises. The explanation of this variation is that when fresh coal is thrown over the fuel bed the "volatile matter" is distilled off and is carried into the combustion chamber where it burns and the temperature there rises. The distillation of "volatile matter" is a cooling process and is undoubtedly the cause of the drop of temperature in the fuel bed and over the fire.



CURVE SHOWING RELATION BETWEEN UNACCOUNTED FOR AND CO LOSS.
TESTS GROUPED ON BASIS OF PERCENT CO LOSS.

RELATION BETWEEN PERCENT CO AND EFFICIENCY, 72*.
CLASSIFIED ON CO BASIS.

CHART NO. 13.
TESTS 89-400.

(2) The peaks in the combustion-chamber-temperature curve, and the depressions in the over-fire-temperature, are wider for Ohio No. 8, a coal high in "volatile matter," than for West Virginia No. 19, a coal low in "volatile matter." The widths show that the "vola-

tile matter" is distilled off and burned in shorter time in the West Virginia coal than in the Ohio coal.

(3) Combustion chamber temperature is much higher with Ohio No. 8 than with West Virginia No. 19. Fuel bed and over fire temperature is higher with West Virginia No. 19 than with Ohio No. 8. This shows that most of the West Virginia No. 19 coal burns on the grate and only little in the combustion chamber, while the opposite is true of Ohio No. 8.

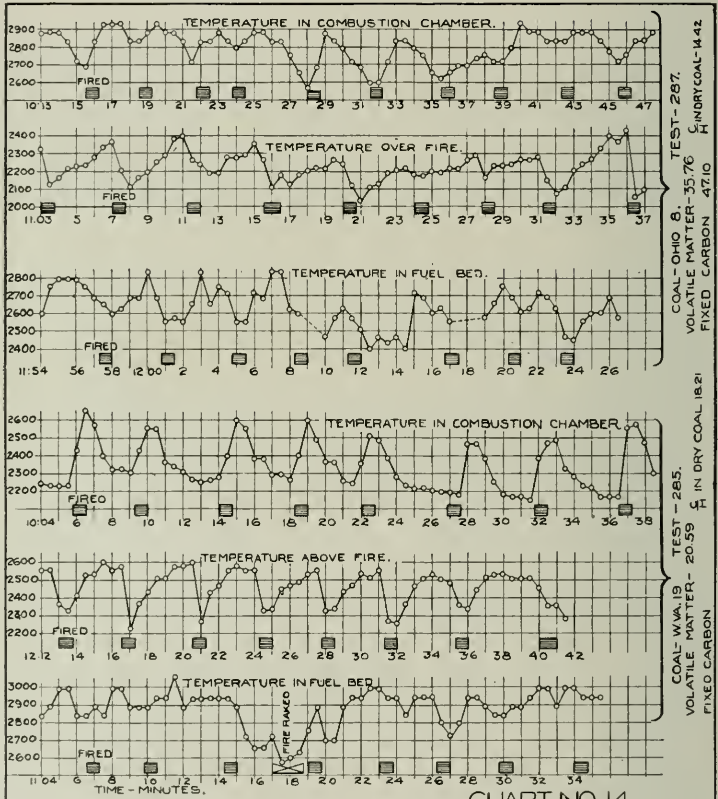


CHART NO. 14.

VARIATION OF TEMPERATURE IN HEINE FURNACE WITH FIRING

OBSERVED WITH WANNER OPTICAL PYROMETER.

The amount of coal charged each firing was from fifty to sixty pounds.

Chart No. 15 gives a comparison of the combustion chamber temperatures taken with the "Wanner optical pyrometer," with the rise in temperature of water from a water-jacketed gas sampler, inserted in the rear of the combustion chamber.

A mercury thermometer was inserted into the water outlet of the gas sampler shown in Fig. 1, and the temperature of the water was read simultaneously with the optical pyrometer. The two curves agree very well, the temperature of the water lagging slightly. The elevation of temperature at A, B, C, in the water curve, is due to reduction of pressure in the water main, caused by water being taken into the measuring tanks for feeding the boiler. The curves should run as shown by the dotted lines—A. D. C.

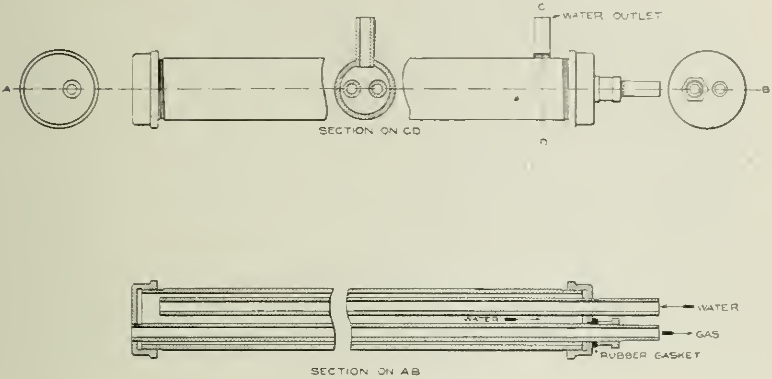


FIG. 1
WATER JACKETED GAS SAMPLER

The true boiler efficiency (E_4) indicates the real measure of the boiler as a heat absorber. It depends largley on the design of the boiler and the baffles, and seems to be effected but little by capacity and initial temperatures. This means, that any one particular boiler will absorb always nearly the same percentage of the heat which is available to it, no matter what the capacity or initial temperature is. This statement is particularly more true about boilers of the Heine type where the heat absorbed by radiation is small in percentage. However this does not mean that high initial temperatures are not desirable. The higher the initial temperature the more heat is available for the boiler and the more heat the boiler will absorb, and the higher the ordinarily used boiler efficiency will be, although the true boiler efficiency may remain constant.

If the true boiler efficiency is to remain nearly constant the ratio of the temperature of the gases leaving the heating surface of the boiler, to the initial temperature of the gases entering the boiler remains nearly constant, both temperatures being reckoned from the temperature of steam.

Chart No. 16, shows graphically the relation in our apparatus between combustion chamber and flue temperature for 212 tests. Tests having doubtful readings are omitted. This chart indicates that in general, the flue gas temperature rises with the combustion chamber temperature.

Take the lowest point on the chart, which is an average of nine tests, the flue gas temperature is 566 Deg. Fahr. and the combustion chamber temperature is 1957 Deg. Fahr. The temperature of steam at 80 lb. of gage pressure is 324 Deg. Fahr. so that the flue gas temperature above that of steam is

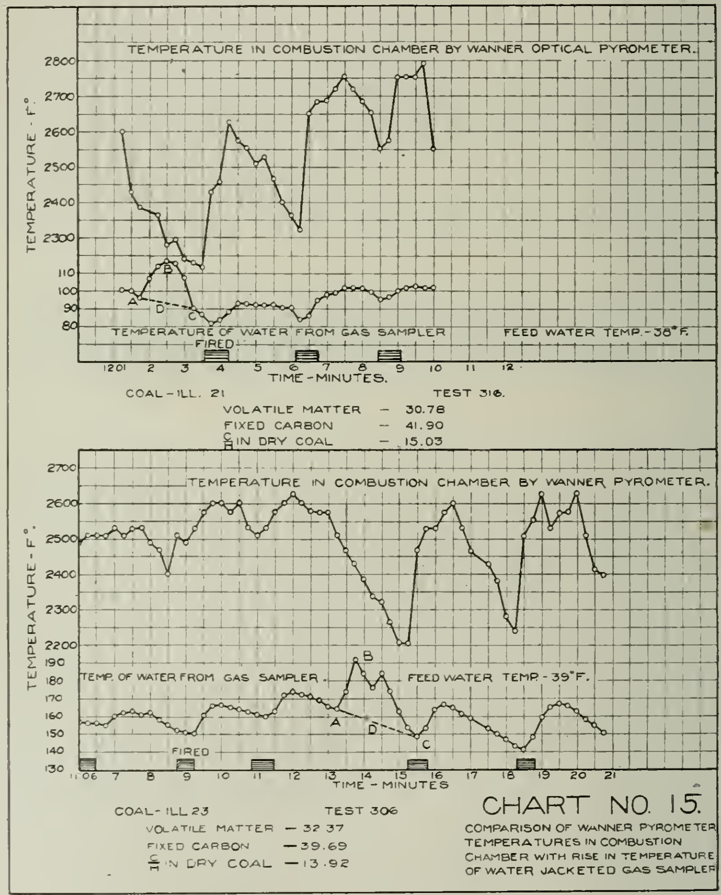


CHART NO. 15.

COMPARISON OF WANNER PYROMETER TEMPERATURES IN COMBUSTION CHAMBER WITH RISE IN TEMPERATURE OF WATER JACKETED GAS SAMPLER

$$566-324=242 \text{ Deg. Fahr.}$$

and the combustion chamber above that of steam is

$$1957-324=1633 \text{ Deg. Fahr.}$$

The ratio then is $\frac{1633}{242} = 6.76$.

The highest point on the chart gives flue gas temperature 628

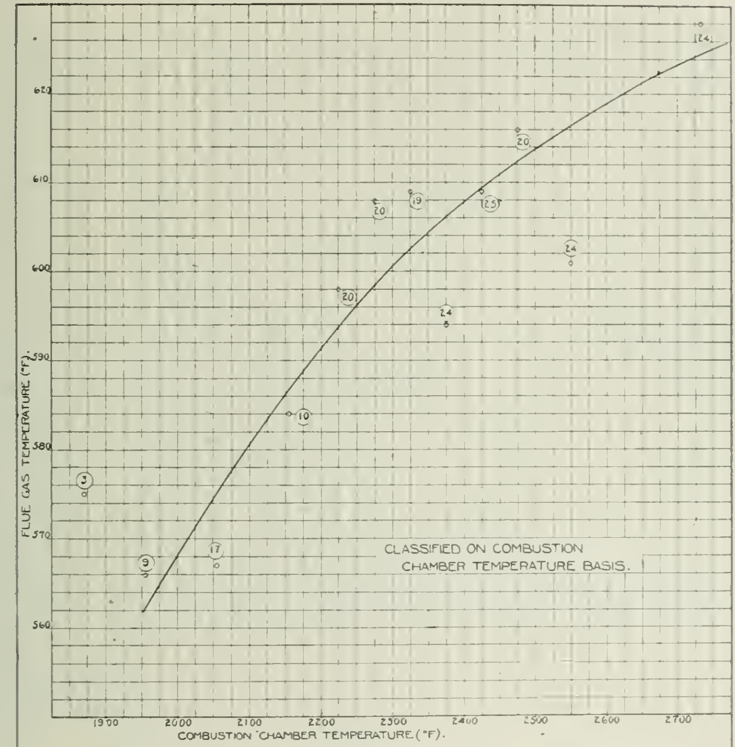
Deg. Fahr. and the combustion chamber temperature is 2730 Deg. Fahr. The flue gas temperature above that of steam is

$$628-324=304 \text{ Deg. Fahr.}$$

and the combustion chamber temperature

$$2730-324=2406 \text{ Deg. Fahr.}$$

$$\text{The ratio is } \frac{2406}{304} = 7.91.$$



CLASSIFIED ON COMBUSTION CHAMBER TEMPERATURE BASIS.

CURVE SHOWING RELATION BETWEEN TEMPERATURE IN REAR COMBUSTION CHAMBER AND FLUE GAS TEMPERATURE TAKEN UNDER STACK DAMPER.

CHART NO. 16.
TESTS 150-400

This is rather a close agreement, for such a wide range of combustion chamber temperatures.

Chart No. 17 shows the true boiler efficiency computed for about 400 of the boiler tests made at the Coal-Testing Plant: the upper curve shows that most of the tests fall close to 82.5 per cent with a fewer and fewer tests falling farther and farther on each side of this value. The curve shows that the probable true efficiency (E_4) of our boiler is about 82.5 per cent. The lower curve of CHART No. 17 is a similar curve for the same tests using the furnace and boiler efficiency (code item 72*). It will be noticed that the sides are not as symmetrical as in the upper curve and that the hump is much wider horizontally. It must be said here that the flue gas analysis and the flue gas temperature, which enter into the calculation of the heat available for the boiler, are the two data of a boiler trial which are the most difficult to obtain accurately. The inaccuracy of the flue gas analysis, lies in that it is very difficult to obtain a sample of the gas which will represent the average product of combustion of the test. The inaccuracy of the flue gas temperature is due to the fact that the stream of gases in the uptake have different a temperature in different parts of the same cross section. Furthermore the thermometer bulb always radiates heat to colder surfaces such as steam drum and boiler tubes to which it is exposed and indicates lower temperature than that of the surrounding gases.*

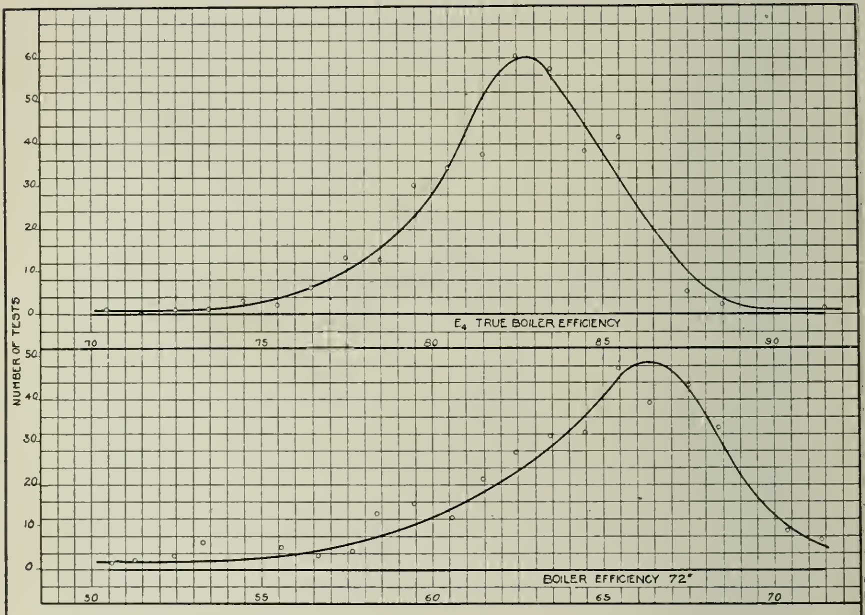


CHART NO. 17.
PROBABILITY CURVE.
TESTS 89-401.

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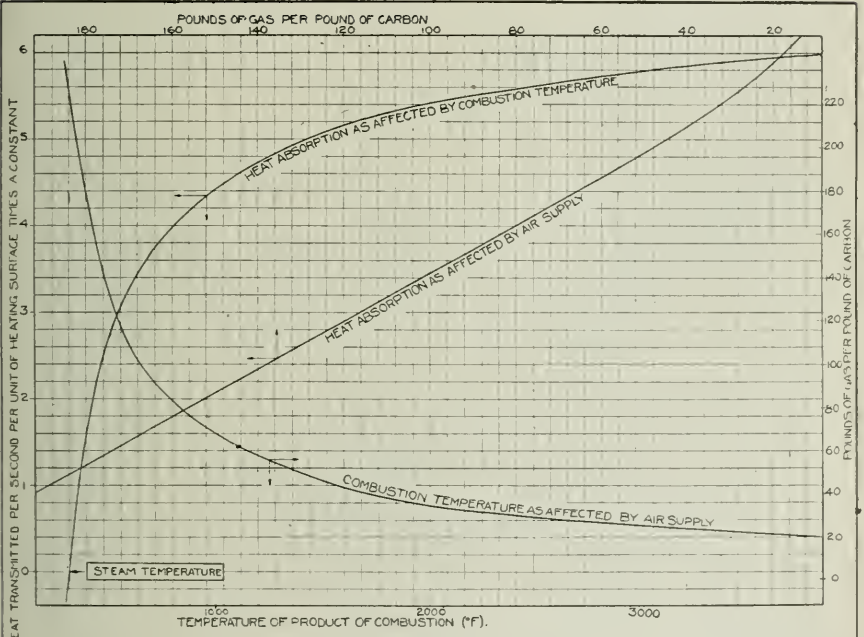
*If visible by a cold or hot surface the thermometer bulb radiates heat or receives heat by radiation. It receives heat from or imparts heat to surrounding gases by conduction and convection. At equilibrium the rate of heat

It may be well in this connection, to mention the four factors which influence the rate of heat transmission through a boiler plate as far as abstraction of heat from gases is concerned, aside from the radiation from fire and furnace wall. These four factors are:

(1) Temperature difference between the gases and boiler plate.
(2) Density of gases or number of molecules per unit of volume.
(3) Specific heat of gases at constant pressure.
(4) Velocity of gas, parallel to the heating surface.

As a rule only the first of these four factors is considered—temperature difference between gases and boiler plate, but it requires only a little consideration to see that as the temperature of the gases is raised, the gas expands and the number of molecules beating



THEORETICAL CURVES OF HEAT ABSORPTION AS AFFECTED BY AIR SUPPLY. CHART NO. 18

radiation is equal to the rate of heat impartation by the gases by conduction and convection. There is a difference in temperature between the bulb and the gases corresponding to the rate of the heat impartation and heat radiation. We know that on a sunny day, a thermometer in the sunshine does not indicate the temperature of the surrounding air, but a temperature much higher than that. Although the difference in temperature is very large, the cone of vision in that case is very small. In the case of a thermometer in the uptake the surfaces on all sides of the thermometer bulb are colder, and although the temperature difference is only two or three hundred degrees, the radiation from the thermometer must be quite appreciable. (This heat radiation causes considerable trouble in temperature measurements in the small boiler experiments.)

against any square inch of heating surface decreases nearly as fast.

The specific heat of gases of combustion with various amounts of excess of air is very nearly constant so that the third item may be neglected.

The fourth item—the velocity of gases parallel with the heating surface of the boiler—is what keeps the true boiler efficiency nearly constant and makes the boiler respond to sudden demands for steam when burning more coal, making more gases and passing them over the heating surface with higher velocity.

The above statement expressed mathematically is,

$$H=KC_p Vd (T-t);$$

where H is the heat transmitted per second per unit of heating surface

K=a constant
C_p=specific heat of gases at constant pressure
V=the velocity of gases
d=the density of gases
T=the temperature of the moving gases
t=the temperature of the dry side of the heating surface.

The above theory of the rate of the heat transmission has been advanced by Prof. John Perry and is published in his book on The Steam Engine and Gas and Oil Engines.

CHART No. 18 shows graphically how the rate of heat transmission is affected by air supply and the temperature of the product of combustion, when one pound of carbon is burned with various supplies of air. The arrows indicate which scale should be used with each curve. The highest curve on the chart shows the relation between the heat transmitted per second per unit of heating surface and the temperature of the product of combustion. It is the above given equation plotted when H, V, d and T vary with varying supply of air for the combustion of one pound of carbon. The middle curve shows the relation between the heat transmitted per second and the weight of the products of combustion. The lowest curve gives the relation between the weight of the products of combustion and the resulting temperature. Using the scale at the right hand of the chart and the lowest curve we find the temperature for any weight of the product of combustion from the scale at the bottom of the chart. Following then the vertical line of the temperature of the product of combustion we find by means of the highest curve, the relative quantity of heat transmitted per second from the scale at the left hand. The same results can be obtained from the middle curve by using the scales at the top and at the left hand of the chart. The working range of pounds of gases per pound of carbon, in steam boiler practice is about from 40 to 16 pounds, which corresponds to a temperature range of 1600 to 4000 Deg. Fahr. of the product of combustion. For this range of temperature, the relative amount of heat transmitted increases from 5.2 to 6.0. After the temperature gets above 2000 Deg. Fahr. very little is to be gained by reducing the air supply, as far as heat absorption by boiler from gases is concerned. The increase in the heat transmitted when the initial temperature is raised from 2000 to 4000 Deg. Fahr. is only about 10 per cent. This gain might be counterbalanced by the loss in incomplete combustion.

The special bulletin of the Boiler Division of the U. S. Geological Survey Coal-Testing Plant, now in print, contains a detailed discussion of the theory of heat transmission.

SPECIAL INVESTIGATIONS AND DEDUCTIONS.

(c) Of the special investigations made by the Boiler Division two are given somewhat in detail in this paper. These investigations are:

(1) Observation of circulation of water through the water tubes of the Heine boiler.

(2) Experiments with a small multitubular boiler to test the theory of heat transmission through boiler tubes.

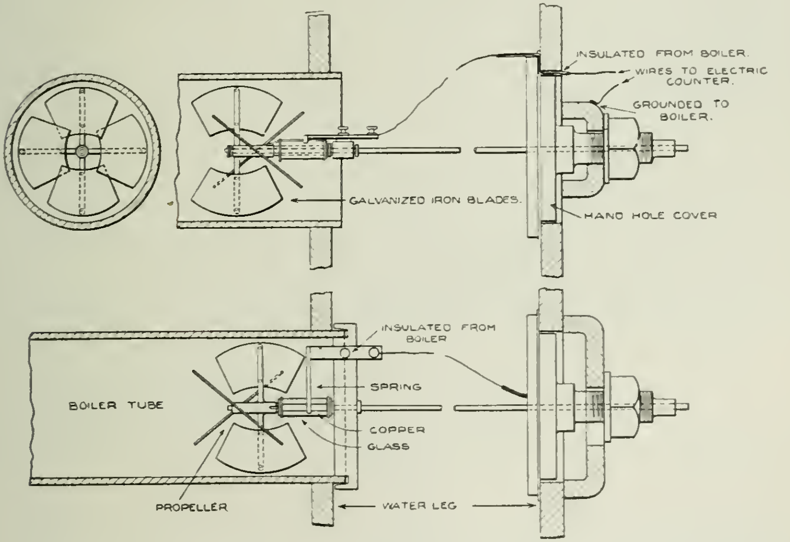


FIG. 2

ASSEMBLED VIEW SHOWING LOCATION OF CIRCULATION INDICATOR IN BOILER.

(1) The observation of the circulation of the water in the boiler tubes was made with a specially constructed circulation indicator shown in Fig. 2. This apparatus consists of a four blade propeller revolving on an axis inside of a boiler tube. To the hub of the propeller is firmly attached a glass commutator with a single copper strip which has a metallic contact through the axis of the propeller with the boiler. Every revolution this copper strip makes an elec-

trical contact with a steel brush which is insulated from the boiler. One terminal of a low voltage battery is attached to the brush, and the other is grounded to the boiler. A telephone receiver placed in the circuit enables an observer to tell whenever the brush and the copper strip on the commutator completes the circuit, and thus count the revolutions per minute. The blades of the propeller make an angle of 30 degrees with the axis of the propeller, and are 1⅛ inch wide, the distance across the outside edges being 3¼ inches. The boiler tubes are 3½ inches inside diameter.

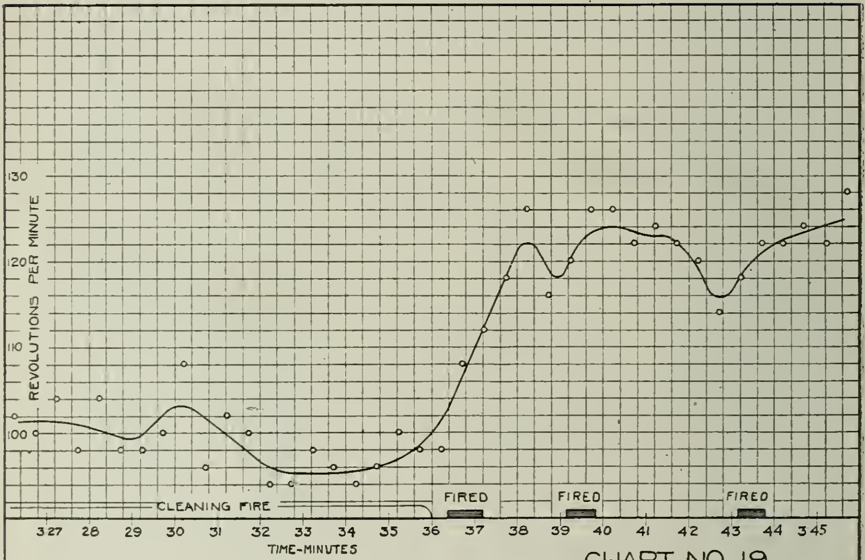


CHART NO. 19.

OBSERVATIONS WITH CIRCULATION COUNTER.
PROPELLER IN BACK OF BOILER MIDDLE
TUBE, 3RD ROW FROM BOTTOM.
TEST NO. 379.

The velocity of water as calculated from the dimensions of the propeller is 11.6 inches per revolution, or taking the friction of the propeller into account it may be taken as one foot per revolution.

Chart No. 19 shows the effect of cleaning fires and of firing, on the speed of water circulation in a tube of the boiler, as measured relatively by the circulation indicator. The circulation is quite prompt in its changes and the values obtained vary considerably. The readings were taken by recording the number of revolutions in a 15-second interval opposite time figures, and from such data the revolutions per minute were calculated and plotted on this chart.

The increased circulation of water during and immediately after each firing, agrees well with the optical pyrometer reading of Charts Nos. 14 and 15.

Chart No. 20 is based on readings taken for several days with the circulation indicator. The total number of revolutions of the indicator was counted for each half-hourly period, and a calculation of the percentage of builder's rated horse power of boiler developed, was made for each such period. The small circles give the positions of points and the numbers nearby give the number of half-hours fulfilling the co-ordinate values of the points. After plotting, the points were averaged in value in both horizontal and vertical strips, each point being included for averaging as many times as indicated by the number in the circle near by. Thus the two curves were determined. It will be noticed that they are very close together, indicating the reliability of the method of working up the data.

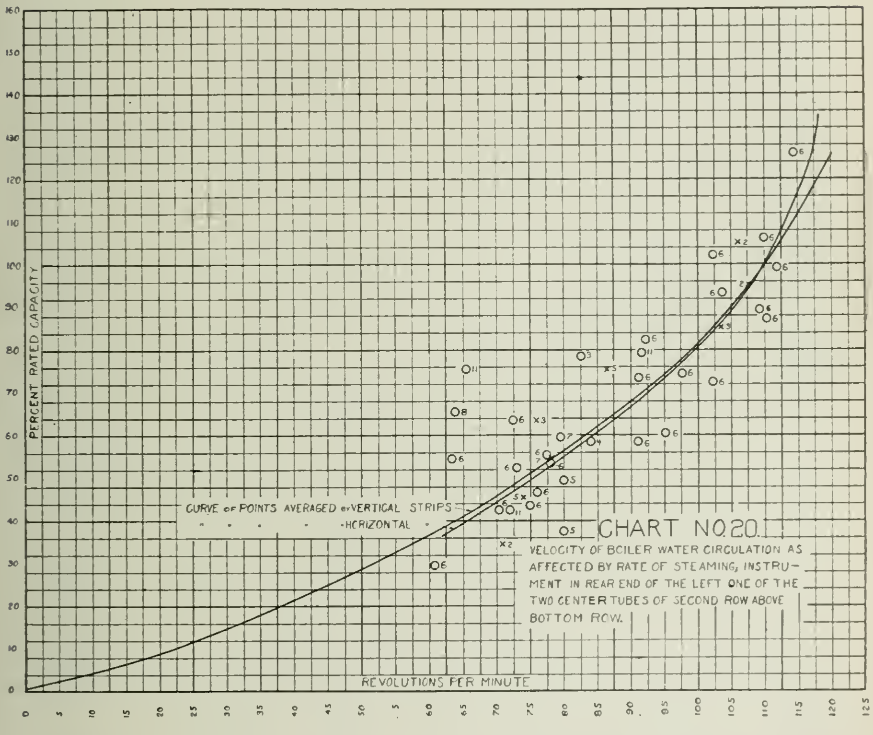


CHART NO. 20.
VELOCITY OF BOILER WATER CIRCULATION AS AFFECTED BY RATE OF STEAMING, INSTRUMENT IN REAR END OF THE LEFT ONE OF THE TWO CENTER TUBES OF SECOND ROW ABOVE BOTTOM ROW.

The important point is that the circulation rapidly drops behind the amount of steam made (percent rated capacity developed), especially at high rates of working. Thus at 70 per cent rated capacity the average rate of revolution of the indicator was 80 per minute. At 105 per cent rated capacity the rate of revolution was 102, whereas to be proportional it should have been 120; the speed of circulation fell about 15 per cent short.

This is reasonable, when we consider that, so far as one can make any speculations, the circulating forces are perhaps roughly proportional to the amount of steam generated and entangled with the rising water, while the frictional resistance to circulation is perhaps proportional to the square of the average velocity of circulation.

This failure of circulation to keep up proportionally with demands on the boiler must decrease the efficiency of the boiler at higher rates of working, by allowing a proportionally larger percentage of the water heating surface to be covered with steam bubbles, thus virtually reducing the heating surface.

At a later date, the same circulation indicator was put in the middle tube of the lowest row in the rear end of the boiler; this was one of the tubes mostly enclosed in clay tiles. The numbers of revolutions per minute for various capacities are given in the following table:

Capacity H. P.	58.2	91.4	118.2	92.2
Revolutions per minute	217	257	273	291
Number of readings....................	78	8	7	12

The number of revolutions at any capacity is approximately three times as great as shown in Chart No. 20, for the second row of tubes just above.

In an earlier experiment the same circulation indicator was placed in the third row of tubes from the top of the boiler and it was found that the rate of revolution was very slow indeed. This indicates that the bottom row of tubes was doing far more work than any other row of tubes, and that as we go from the bottom row up, the amount of work done decreases very rapidly.

The probability is that the bottom row of tubes absorbs a large portion of the total heat, mostly on account of conduction through the clay tiles and radiation onto the exposed portion of the tubes in the rear over the hot brick-work. This probability makes it easy to realize that the efficiency of the boiler, as a heat absorber, may well rise far more rapidly with increasing furnace temperature, than is indicated by the equation for heat absorption from the gases due to convection only.

(2) An apparatus designed for experiments relating to the laws governing the rate of heat transmission from the gases through the boiler plate, is shown in Fig. 3. It consists of an electric furnace, small horizontal multitubular boiler, a small surface condenser, and a steam ejector for producing draft.

The electric furnace is made of six coils of No. 13 pure nickel wire which is wound around rectangular pieces of asbestos slate ⅛ in. in thickness. These coils are placed vertically in a trough of asbestos slate, with a space of about ⅜-in. between them and baffled in such a way that the air passes three times through the furnace before it leaves it.

The boiler is 8 in. long and the shell is 4 in. in internal diameter. There are ten copper flues of 3-16-in. internal, and ¼-in. external diameter; this making the thickness of the metal 1-32 of an inch. The heads of the boiler are covered with a layer of asbestos paper about ¼-in. thick so that only the heating surface of the flues remains effective. The boiler is equipped with a gage glass, pipe for

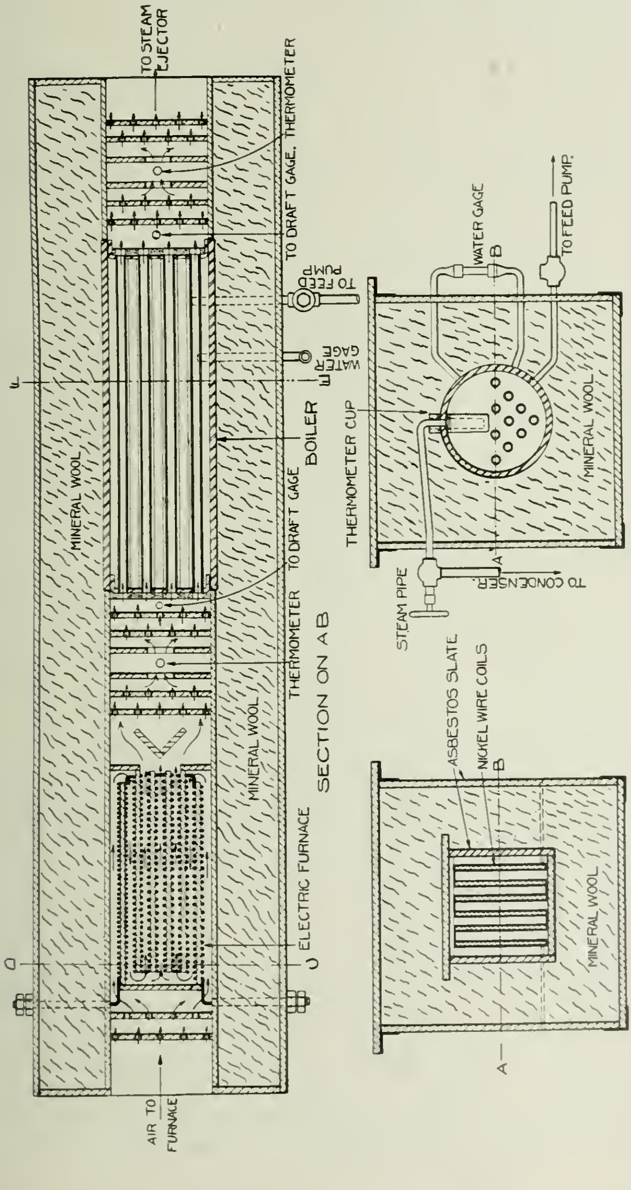


FIG. 3.
APPARATUS FOR DETERMINING THE RATE OF HEAT TRANSMISSION THRU BOILER FLUES

feeding in water, pipe for pressure gage and thermometer cup for getting the temperature of the steam. The thermometers used for measuring the temperature of gases entering and leaving the boiler are screened by perforated pieces of asbestos slate from the radiation of the furnace and boiler and also from radiation to the outside. The two screens nearest to the thermometer have only one square hole in the center so that the stream of heated gas is contracted around the thermometer bulb. This precaution makes the thermometer reading represent more nearly the average temperature of the streams of gases. All the boiler connections and the trough around the boiler are covered with hair felt to reduce the radiation losses to a minimum. It is the intention to use in these experiments three boilers of different lengths and to determine the effect of the length of flue on the heat absorption, and also to test flues of different diameters.

The surface condenser is made of two concentric copper tubes, the inner of these is for steam and the outer one for a stream of cooling water.

The steam ejector for producing draft is a standard ⅜-in. pipe, placed in the center of a contracted pipe made of galvanized sheet iron which takes the gas away from the rear end of the boiler.

Before a test is started the apparatus is brought to the temperature at which the test is to be run. After starting a test, all conditions are kept as nearly uniform as possible.

On the tests so far done the following readings have been taken:

ta=Temperature of air entering furnace.
T=Temperature of air entering boiler.
tf=Temperature of air leaving boiler.
ts=Temperature of steam.
tw=Temperature of feed water.
P=Steam pressure.
d=Draft of air entering boiler, in inches of water.
D =Draft of air leaving boiler, in inches of water.
W=Water condensed.
M=Weight of air passing through the boiler, per second.

The weight of air, M, passing through the boiler per second is obtained from the relation

$$W\,[965.7+(212-tw)]=.2375\,M\,(T-tf)$$

Hence $M = \dfrac{W\,[965.7\ \ (212-tw)]}{.2375\,(T-tf)}$

The volume, V, of the air entering the boiler is determined from the relation

$$\frac{V}{12.387}=\frac{T+460.8}{492.8}$$

Hence $V = \dfrac{(T+460.8)\quad 12.387\times M}{492.8}$

and the velocity of the air entering the boiler

$$v = \frac{v \times 144}{(3/16)^2 \times .7854}$$

In the calculation above indicated, W is reduced to water condensed per second, then the velocity v is in feet per second.

Table No. 7 gives data and results of several tests made with this small experimental boiler to determine the effect of velocity of gases on the rate of heat transmission.

TABLE NO. 7

EXPERIMENTS WITH THE SMALL BOILER (FIG. 3) TO DETERMINE EFFECT OF THE VELOCITY OF GASES ON THE RATE OF HEAT TRANSMISSION.

	Drafts in inches of Water		Temperature in degrees Fahr.				
Test No.	Air Entering Boiler	Air Leaving Boiler	Air Entering Boiler	Air Leaving Boiler	Steam	Heat Transmitted per second B.t.u.	Velocity of air entering tubes, ft. per second
16....	About 0.0	3.0	315.	215.	211.	.0548	23.5
15....	"	5.2	316.	219.	211.	.0866	38.6
17....	"	10.1	310.	217.	211.	.1214	56.1
12....	"	.5	506.	244.	211.	.0869	17.6
11....	"	1.0	505.	252.	211.	.1091	23.0
5....	"	3.0	507.	259.	210.	.2269	48.9
4....	"	3.0	507.	261.	210.	.2385	52.0
10....	"	5.2	500.	261.	211.	.3766	83.5
13....	"	9.2	493.	265.	211.	.3742	86.6
8....	"	1.0	707.	289.	212.	.1922	29.6
7....	"	2.0	708.	306.	210.	.3380	54.3
6....	"	3.0	708.	304.	211.	.4153	66.7
9....	"	4.3	700.	305.	210.	.4645	75.5
14....	"	8.9	689.	312.	211.	.7028	118.5
20....	"	2.0	892.	289.	211.	.4088	50.6
22....	"	4.0	903.	307.	211.	.6150	77.8
19....	"	8.5	898.	307.	211.	.8927	113.4
18....	"	1.0	1118.	287.	210.	.4171	43.8
21....	"	3.0	1120.	340.	211.	.9023	100.8
23....	"	8.2	1097.	314.	212.	1.2960	142.7
26....	"	1.0	1312.	287.	210.	.5501	52.7
25....	"	3.0	1313.	377.	210.	.9563	100.3
24....	"	6.6	1300.	387.	213.	1.5180	162.3

CHART NO. 21, shows the relation of the velocity of air to the rate of heat transmission. The points on the chart were obtained by plotting the last two columns of Table No. 7. The figures near each point indicate the average temperature of air entering boiler for each test. The most striking feature in the chart is that all the points of nearly the same temperature, fall in the same straight line. This means that when initial temperature remains constant the heat transmitted per second is directly proportional to the velocity of air. Another striking feature is that as the temperature of gases entering the boiler rises, the constant temperature lines fall closer together. This means that when the velocity of air is constant, the heat absorption increases at a decreasing rate, as the temperature becomes higher; that is, the heat absorption is not directly proportional to the temperature of the air. The same increase at low temperatures is much more effective than at high temperature.

There is one objection that might be brought against the results plotted in Chart No. 21, and that is that the water condensed per second, was used in calculating the velocity of the air. This method of calculation makes the velocity somewhat dependent on the rate of heat absorption and tends to bring the points into a straight line. Experiments are now being conducted with improved apparatus in which the electrical energy used in heating the air is accurately measured and will be used in calculating the velocity of gases, which velocity will then be independent of the water condensed. The fact that the heat absorption increases when the velocity increases remains, although more complete experiments with improved apparatus may show that the relation between heat absorption and velocity of gas deviates slightly from the straight line function.

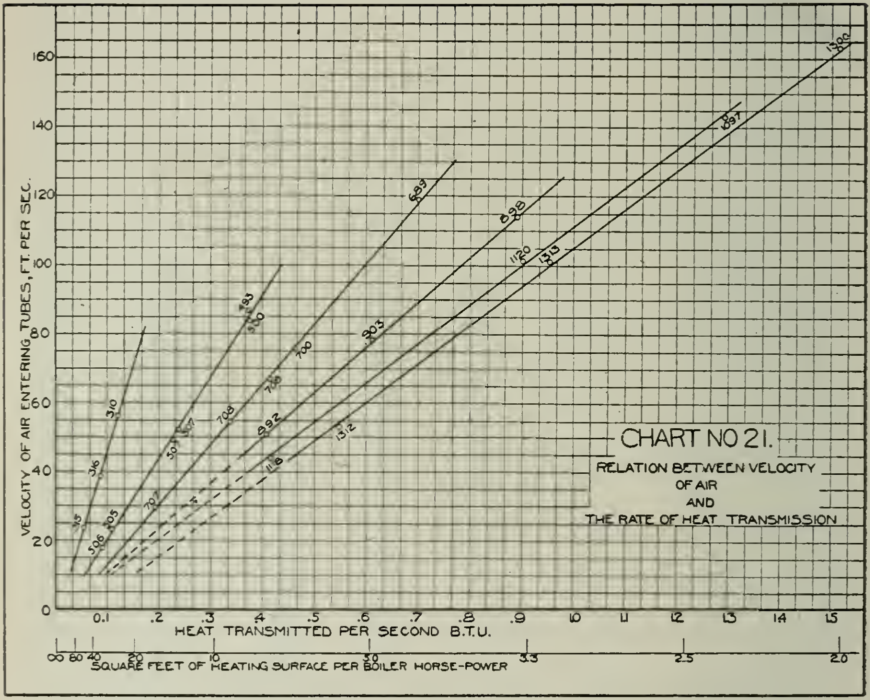


CHART NO 21.

RELATION BETWEEN VELOCITY OF AIR AND THE RATE OF HEAT TRANSMISSION

DISCUSSION.

President Abbott: In the earlier part of this paper, the author states that;

"The work of the Boiler Division of the Fuel Testing Plant may be divided into three parts:

"(a) Routine steaming tests made on various kinds of fuel.

"(b) Analytical study of the properties of coal, the conditions under which steaming tests were run and the relation of the two to the economic results.

"(c) Special investigations and deductions pertaining to the work of this division."

Any engineer of fair ability can conduct a series of tests if the work is laid out for him, and a chemist with a fair knowledge of his profession can give a correct analysis of the fuels used. This is as far as most boiler tests go, but in this case if the work were to stop there it would be practically useless. I think I may say that that is as far as the Government intended this work to go. The gentlemen in charge of these tests were not slow in realizing this fact, and (I think surreptitiously at first, certainly very cautiously) they began scheming for some means to make their work of practical value. It is my experience that employers generally, those who pay for the coal and pay for the tests, have very little appreciation or use for the deductions which may be made from tests further than those which give the evaporation. But I think the education of the Government officials in that respect has now advanced to a point where it is safe for the gentlemen in charge of these tests to say to them, when asking for means to continue those tests, that in this additional information lies the real value and reason for continuing the tests.

There has been expended upon this work tens of thousands of dollars, the results of which would be gathered up into Government reports, to be put away on a shelf to accumulate mould and dust, were it not for the fact that the Geological Survey is fortunate enough to have placed this work in charge of gentlemen who appreciate what the real value and what the real purpose of these tests should be, and who have woven into the work and over it and through it a scheme for deducing from this great mass of tests, principles which no coal user could undertake to work out. One of these gentlemen under Prof. Breckenridge, upon whom has fallen the work of deducing conclusions (as outlined in the third paragraph of the sub-divisions of this work) and in arranging the work so as to bring out these conclusions, is Mr. W. T. Ray, whom I will call upon to tell us something of his work.

Mr. W. T. Ray, JUN.M.W.S.E.: I wish to thank President Abbott on behalf of the Survey and for myself for the half flattering and half questionable introduction. Nevertheless, I appreciate the opportunity of appearing before you. I shall not take time to go over any of the curves in detail. All I wish to say in regard to that, is that Mr. Kreisinger, Mr. Barker and myself are here this evening ready to try to answer any questions that may be asked, and ready to welcome any criticisms or suggestions for the future. Of course, more or less, shut up as we are, in an inner technical field of routine work, we are apt to lose sight of the larger problems—the real problems of the work. However, I do wish to thank

Mr. Abbott, and to approve his remark to the effect that the value of any experimental work, does not lie in doing it, so much as in studying it after it is done. It is a universal mistake, of which engineers are guilty; to make a lot of tests and then, instead of stopping to study the results of the tests, they make some more. We have been unfortunately rushed in that respect, and this has required, on the part of Prof. Breckrenridge and myself, a good deal of resistance to that general feeling of haste that nearly everybody has, and I must say that the people who have been most guilty of urging us on to make tests rather than to draw deductions from them, are mechanical engineers, rather than physicists or chemists.

In regard to this paper, I will call your attention to page 320, the middle of the page, portion (2). This work was undertaken to study the laws of heat absorption by boiler heating surfaces so far as connection is concerned, not considering absorption on account of radiation. Mr. John Perry deduced the laws of the heat absorption, which was put on page 316 in simple English.

Referring again to page 320, I wish to say that this work recently begun and in progress now, and which will be continued to other sizes of tubes and other styles of boilers (including water tube boilers), amount of draft, etc., was designed to check out Mr. Perry's theory, which so far has held absolutely. If the mathematical predictions continue to be verified, I can say that without doubt, it will put the steam boiler on the same sound, certain mathematical basis as the electric generator is now; when a man designs a dynamo he knows what its efficiency will be before it is built.

I notice that Prof. Breckenridge omitted from this paper a paragraph which was in the Study of Four Hundred Boiler Tests (from which most of this matter was taken) called "Commercial Considerations." The beauty of Mr. Perry's ideas are that he has not only put the steam boiler on an absolutely sure basis, but he has pointed out methods of increasing the performance of the boilers at least ten times. That is, a dollar's worth of metal properly employed may perhaps result in the generation of ten to twenty times as much steam and at higher efficiency than is done now.

Commercial Considerations.—The statements, theories and proposals made in this Review are widely scattered and probably have not been plain because mathematically involved. For this reason a short summary will be made here of the possibility of so improving the system of working steam-turbine plants as perhaps permanently to keep them above commercial competition from gas producer and engine plants, in large powers; of course there is little doubt about the great field immediately awaiting the gas engine in smaller plants, say under 5,000 horse power. All these suggestions are tentative only; work will gradually be prosecuted by this Division along the lines of trying-out the ideas about to be stated.

Boilers.—The authors see no reason why boilers cannot be constructed, and probably operated with entire satisfaction, such as will produce about ten times as much steam per square foot of heating surface as is now done, and with no difficulty in obtaining dry steam. The efficiency from coal to steam should easily be made considerably higher than a good performance of today. This will mean only a fraction of the investment in steam plants, buildings and real estate. Mr. John Perry states in his book on "The Steam Engine and Gas and Oil Engines" that he thinks boilers should easily be made to do ten times the work they do at present, possibly twenty.

Furnaces.—Likely it will be found on attempting this reduction of dimensions and cost that the limit will be, not in the boiler as such, but in the combustion chamber. Burning a large amount of coal on a small grate area is almost altogether a question of draft and continual riddance of ash; but the rate of travel of gases thru a combustion chamber is dependent practically only on the amount of carbon burned per unit of time, being almost the same no matter what the air supply per pound of carbon. As combustion chambers are now constructed for Western coals they are too "small," but small is a word not to be understood in this connection as referring to volume or length alone; by a small combustion chamber is meant one in which either the time spent by the gas in traveling from the front to the rear of the boiler is short or else one in which the mixing devices are inefficient or absent. In the work on mass action it was stated that mere length of combustion chamber counts for little; that mixing is what counts; and thus there is a possibility of enormously increasing the efficiency of a combustion chamber as a burner of volatile matter. Effort in completing a steam generating outfit of small dimensions must be largely concerned with constructing a combustion chamber having in it many gas mixing constructions.

Turbines.—The work on turbines is provisional only but it is felt that all of the assumptions made are on the side of safety; that is, that the over-all efficiency of the turbines working with high superheat and low pressure would probably be greater than estimated, and many per cent higher than anything yet achieved.

Inasmuch as the boiler plant is at present the expensive portion of a steam plant and as it is probably possible to cut its cost down to a fraction of the present cost and at the same time obtain a higher efficiency, it is felt that there is good ground for anticipating an enormous improvement in the production of steam power within the next few years. If so it will not be the first time that a new arrival in a field has spurred on older forms of enterprise to a higher prosperity than they ever dreamed of before. The competition of the gas engine may be the best thing that ever has happened to Steam Engineers.

There have been tested lately, under good auspices, in Germany some automobile steam engines and boilers of less than 30 H. P., which gave one horse power on one pound of coal.

President Abbott: I would like to have it made a little more clear the means by which the capacity of a boiler is to be so enormously increased.

Mr. Henry Kreisinger, M.W.S.E.: The capacity of a boiler can be increased by increasing the velocity of the products of combustion along the heating surface. In marine and locomotive practice this is being done every day. With these classes of boilers, the capacity is doubled or tripled by increasing the draft and burning two or three times the amount of coal, thereby producing two or three times the amount of gases which pass two or three times as fast along the heating surface, thus doubling or trebling the rate of heat transmission. A locomotive boiler develops a boiler horse power on three square feet of heating surface or even less, whereas in a stationary boiler ten square feet are required to do the same amount of work. Of course, in a locomotive boiler the high capacity is always accompanied by a considerable drop in "over all" efficiency; however, this drop in efficiency is largely due to less complete combustion of the fuel in the comparatively small combustion space of the locomotive furnace. In stationary boilers the loss in incomplete combustion can be greatly reduced by a furnace properly designed as regards the rate of combustion and the nature of the coal.

Prof. Breckenridge suggested that I give some additional information about the temperature changes shown in charts Nos. 14 and 15. To what is said about the charts in the paper I may add that the length of the small cross sectioned areas at the bottom of each curve indicate the time occupied by each firing. As shown in the chart the average length of time taken to charge six shovelfuls is about 45 seconds.

Chart No. 15 has a historical connection with Chart No. 10, which shows that the combustion chamber temperature has but little influence on the over all efficiency of a boiler in our apparatus. We had been measuring temperatures in the combustion chamber and plotting these with the efficiencies of the tests in the hope of finding that high initial temperature increase the efficiency. When our results showed that the efficiency remained nearly constant, no matter how high the initial temperature was, we thought that the optical pyrometer readings were wrong and that we were looking at luminous flames which were not as hot as they appeared to be by the optical pyrometer. When we used the apparatus shown in Fig. 1 for sampling the gases in the combustion chamber, we noticed that the cooling water always came out of the sampler hotter immediately after firing. It occurred to us that by taking simultaneous temperature readings of the cooling water as it came out of the sampler, and of the temperature in the combustion chamber with the optical pyrometer, we might get some data as to the reliability of the relative readings of the optical pyrometer. We did this, and found that the variation in temperature of the cooling water agreed quite well with that observed by the optical pyrometer, showing that the temperatures observed with the latter were relatively correct.

The efficiency curves of Charts Nos. 9 and 10 are applicable to our apparatus only. With a better furnace than ours, the efficiency curve would approach the top curve of Chart No. 18. With a furnace having little or no combustion space the efficiency would undoubtedly drop with the rise of initial temperature.

Mr. Perry Barker, JUN.M.W.S.E.: There are two very interesting charts not shown in the paper, where a special classification was made. We separated all the coals according to the states from whence they came and sub-divided those again into seams and then grouped the results of the tests. We recorded the percentages of smoke from the different coals from the different states; we also classified the percentage of smoke on the basis of the ratio of carbon and hydrogen in the volatile matter.

Dr. R. S. Moss, M.W.S.E.: I have listened to this paper with a good deal of interest. In regard to the percentage of CO2 content, I would ask Prof. Breckenridge whether or not it is a fact, that the greater CO2 content in the stack gases indicates a better combustion than a lower content?

I believe Mr. Kreisinger stated that in passing the gas sampler through the furnace steam issued from the exit. As I understand it then, we must assume that the stack temperature must have been very high. I would ask why it was necessary to use this particular method in taking samples of gas?

In regard to the stratification of gases; anyone knows that the hydrogen content in coal (from its specific gravity) is much lighter than the carbon content. Is it not possible that we may have a stratification of those gases? Is it not possible that we may get an incomplete mixture of the products of combustion from the furnace?

Mr. R. B. Holbrook: I would ask whether these gentlemen recall whether they found some particular rate of combustion per sq. ft. of grate of these different coals, more economical than others?

Mr. W. S. Huyette: In the paper there is shown a device for measuring the circulation of water in the boiler tubes. I would call attention to the fact that in 1892 Mr. Thornycroft, of England, conducted experiments along this same line, using a device similar to this for the same purpose.

Dr. Moss: Prof. Breckenridge has stated that the higher the volatile matter, the higher the ash. I would like to know if he can give the dividing line between the higher content of ash as compared with lignite. Take the Wyoming coals; I found they ran about 2 to 6 per cent ash, with a very high volatile content. The western coals will run, of course, about 34 to 40, and Indiana No. 6 will run 40 or 42 per cent volatile matter. The Pittsburg coal runs about 44 per cent with a much smaller ash content. I do not see how Prof. Breckenridge can prove conclusively that the high volatile coal necessarily carries a very high ash content.

Regarding the volatile ingredients in the coal; in our western coals, I think, it is understood that while we will assume this 34 per cent as against Pittsburg coal, the value in heat unit content of our western coals in volatile matter is much lower than with Pittsburg coal. I explain that from the simple reason that the heavy hydro-carbon content of our western coals is lower than the heavy hydro-carbon content of eastern coals.

Mr. A. J. Saxe, M.W.S.E.: I took some CO2 samples the other day, and I thought from the looks of the fire the gases ought to go to about 12 per cent CO_2, and I got only 1½ per cent. I took several samples and wondered why it was, but I found out that the sampling tube was so long that it reached across the furnace, and admitted air from beyond the furnace.

Mr. Huyette: I would ask whether or not any deductions, observations or comparisons have been made in the variations of the CO_2 content in connection with the temperatures of the escaping gases leaving the boiler.

A Visitor: We very often find that in pamphlets sent out, describing CO_2 instruments, that the increase in CO_2 is accompanied by an increase in efficiency; I would ask whether or not this is something that has been deduced from a theoretical consideration, or whether it could be demonstrated in practical experience?

Mr. C. S. McGovney: It is a little surprising to learn that the combination of the numerous and variable factors which effect the transmission of heat from the hot gases to the water within the boiler, should so persistently arrange themselves as to produce a constant ratio as shown in the curve No. 2, Chart 10.

The thickness of the film of dry steam in immediate contact with the tube surface should increase with the temperature and this must be found to have a very considerable effect in offsetting the advantages of high temperature.

In regard to the item "furnace efficiency"; I should prefer to retain the usual conception that it includes an expression of the completeness of combustion and the temperature of the gases delivered to the boiler tubes. Improvement in boiler construction must take this temperature into account.

Relating to the true thermal efficiency of the boiler the method as indicated under "E4" gives that value for any particular boiler and is a useful conception. Calculations made in that manner for the experimental boiler at the Engineering Experiment Station show a thermal efficiency above 80 per cent. Such a definition of thermal efficiency of boilers would fail to give direct means of exact comparison of the standard boiler and boilers having positive circulation or boilers with economizer attachments so enclosed as to be inaccessible for temperature measurements.

There is in the paper presented this evening a response to the call for more refined methods of calculation and expression in the consideration of boiler problems. We should accustom ourselves to deal more largely with the thermal quantities involved and these should be the basis of all calculations.

In calculating the heat supplied to the boiler or determining the efficiency of combustion we should subtract the heat value of the combustible passing into the ash and refuse. When drippings from the grate are allowed to fall into the ash pit this refuse combustible is nearly pure coke carbon and may have as much as 4 per cent greater or less heat value than the combustible fed to the grate. For Illinois coals fired on chain grates this variation is generally less than 0.3 of one per cent.

Mr. A. J. Saxe: Where is the point in the furnace that we should take our gases to get the highest percentage of CO_2; is it just at the point where the flame dies out?

Mr. C. H. McClure, M.W.S.E.: There is a point in Chart 13 to which I should like to call attention. We have a curve that shows, for increased loss due to formation of CO, a corresponding increase in unaccounted-for loss. It is probable that this unaccounted-for loss could be accounted for by escaping hydrocarbons, and if we could determine them by direct analysis it would furnish a satisfactory explanation of discordant results, often obtained in boiler trials where the conditions are such as to permit of but one explanation, i. e., incomplete combustion, not of the fixed carbon which falls into the ash pit, for that loss is easily ascertained, but of the volatile portion of the coal. The conditions that will produce CO are practically the same, as will produce hydrocarbons, i. e., insufficient air supply, or, more properly speaking, an improper distribution of air supply and a failure to obtain a thorough mixture with the available air. Certain calculations that I have made and present in the accompanying diagrams A and B show how great losses from this source may possibly be. Two of the principal products of the distillation of coal in gas retorts are methane, CH_4, and ethylene, C_2H_4. It is reasonable to suppose that similar conditions in the furnace, i. e., distillation of the volatile matter in the coal without sufficient air for combustion, will produce these same gases. It is

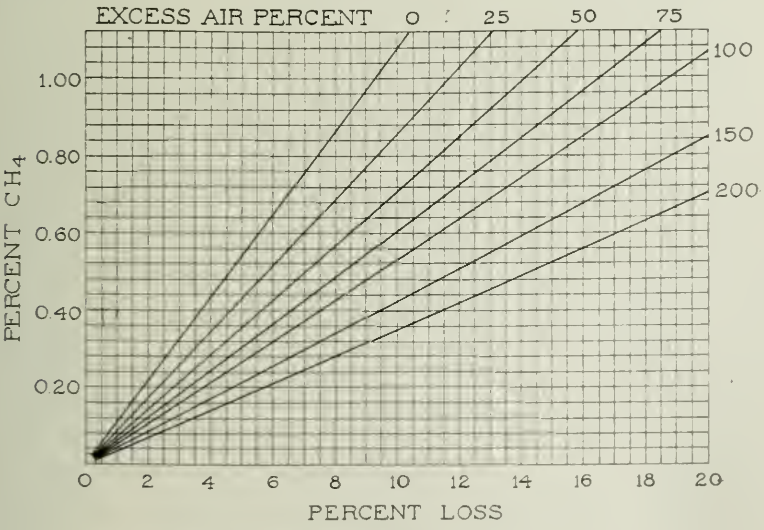


Fig. A—Loss due to Methane in Flue Gases.

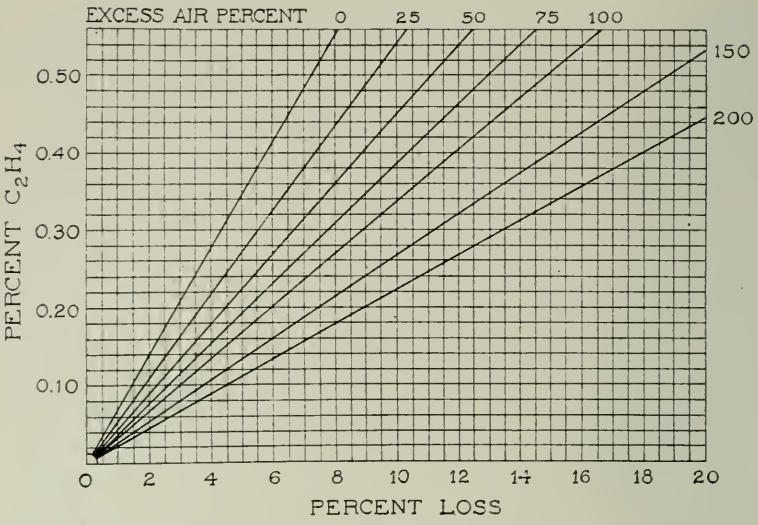


Fig. B—Loss due to Ethylene in Flue Gases.

also possible that small amounts of propylene, C_3H_6, are also formed which would give greater losses, volume for volume, than would ethylene, C_2H_4. Minute quantities of each of these three gases occurring at the same time would, in the aggregate, cause considerable loss.

In regard to Chart 12, it seems to me that the loss in efficiency of the furnace is due to incomplete combustion, or at least improper air supply. The coal may have been so distributed on the grate as to allow just sufficient air for complete combustion at one point and not enough air at another, a favorable condition for the production of CO and hydrocarbons together with a high CO_2. High CO_2 is considered as very desirable in furnace practice because it indicates a minimum of excess air. It may, however, indicate insufficient air which might be productive of far greater losses than a considerable amount of excess air. The 13 per cent of CO_2 is, of course, not the maximum CO_2 that can be obtained from complete combustion of bituminous coal, but from the fact that the CO_2 is only 13 per cent instead of about 18 per cent (the theoretical percentage with no excess air), it may not necessarily be assumed that an excess of air was present, for the excess shown may be due to leakage, or from the taking of gas samples at the wrong place, or from an insufficient quantity of air to form the theoretical CO_2, the remaining carbon of the coal escaping in the form of CO or hydrocarbon.

Dr. Moss: Regarding the amount of CO_2 content, I want to further state that we have had published at one time and another the amount of CO2 that has been obtained by various observers. I read a few days ago a statement that 17 per cent of CO2 had been obtained. It is evident that the party who took that sample was not qualified to do so.

President Abbott: What do you say is the highest possible percentage of CO2 in burning our western coal, with a theoretical amount of air?

Dr. Moss: 14 per cent without danger of CO or incomplete combustion.

Mr. F. Chauvet: In regard to the stratification of gases and also hydrocarbon, I would like to know what has been done in determining hydrocarbons. In taking gas samples I found considerable stratification, and in some cases the CO2 reached as high as 16 and 17 per cent. That I should think would be the place to look for hydorcarbons.

President Abbott: What was the average CO2?

Mr. Chauvet: Along the sides of the boiler setting, it ran probably 4 or 5 per cent, but we did not average up the whole cross section of the passing gases; it is difficult to do that. There were areas showing 16 and 17 per cent of CO2 in the first and second pass. Further, I have noticed, in taking gas samples, where considerable quantities are drawn, that the sampler acts as a condenser, and there is considerable condensation which may not all be water, and it may be possible that these were lower hydrocarbons and synthetical products, and that they might contain a considerable amount of the losses. I have noticed this repeatedly, and I should think it would be interesting to determine by analysis these products, and see what bearing, if any, they may have on the unaccounted-for losses.

Mr. Saxe: I would ask Mr. Chauvet where he got the largest percentage of CO2; he says that on the sides it ran about 4 per cent. I suppose the 16 and 17 per cent must have been taken from the center of the furnace.

Mr. Chauvet: About half way up the first pass between the seventh and eighth row of tubes.

Mr. A. Bement, M.W.S.E.: Usually the engineer is interested in the attainment of high efficiency, or, in other words, securing a maximum result with a minimum expenditure. It is to be regretted that the work of the Fuel Testing Division of the Geological Survey should be conducted at the low efficiency that it has been. The original idea governing the work of the boiler division, for example, was that it would be desirable to burn a large variety of coal from various places and report what proportion of heat would be realized in steam for each of the tests, crediting the coal with a greater or lesser value according to the result in each case. It is unnecessary at this time to present any argument to show that such tests in themselves could only be of but little value, involving the expenditure of a large sum of money in the use of a boiler and grate as a calorimeter for the purpose of heat measurement, a very unwise thing, because a boiler is not only a very crude and inaccurate calorimeter but a very expensive device for the purpose. All of the real value expected from the work as originally contemplated could have been done by the chemical division very much better and at far less expense. In fact, the chemical department did determine and report the heating value of each sample of coal which the boiler division used and made it entirely unnecessary for the coal to have been burned because the data of the chemical department was much more accurate. It would, however, appear that it is necessary in Government work to often make large expenditures of money to be used in work of little or no value. For example, the river and harbor appropriations is a familiar instance; some important harbor may need improving, and for that purpose require an appropriation which certain members of Congress will not vote for, unless they can also have some money spent on some stream of no consequence but in their locality. So it would seem that it was necessary to obtain an appropriation for this fuel work so that the coal of various people could be burned up indiscriminately just to make them feel they were having attention. It certainly is to be hoped that the work of the future may proceed on rational and scientific lines because the amount of money which has been expended at St. Louis has reached an enormous figure, and it is a burden which the Geological Survey cannot carry much longer. The appropriation, I understand thus far, is as much as $750,000, and any of the large private corporations maintaining a staff of technical people could have easily accomplished more for $100,000 than the Government will with the entire $750,000.

Referring particularly to the work of the boiler division, I consider that most of the credit for useful results that have been obtained is due to the young men who have occupied subordinate positions, more particularly to Messrs. Ray and Kreisinger, especially Mr. Ray, and this fact has caused me to realize to what a large extent the Chicago Edison Company has been instrumental in propagating intelligent investigations along these lines. Its engineers have been leaders and set an example, which has been followed by many people, tending toward a better understanding of these complicated problems which concern fuel and its utilization, requirements for smokeless combustion and high efficiency in steam generation. It was with this company that Mr. Ray obtained his first experience in the work which he has been conducting at St. Louis, and out of the results of these coal burning experiments which otherwise would have been useless, he, with Mr. Kreisinger and the other young men, have extracted something of value as shown by the diagrams in the paper, and it is for this reason that I consider credit particularly due to them, and in justice, I think the fact should not be overlooked that they have extracted this matter from the mass of available data at considerable labor and expense to themselves. The conclusions presented by these diagrams, however, would have been much more accurate and definite, had the experiments been expressly conducted for the purpose of determining the particular features. For example, referring to the diagram showing the relation between efficiency obtained and moisture in coal used: if the ash content varied in these tests, some of the result would be caused by it, rather than to difference in moisture, and the effect would be due in a measure to the presence of ash as well as moisture. Mr. W. L. Abbott presented a paper some time ago* which I think can serve as a pattern for future investigation, because it not only gives results of work on this plan, but concerns itself with the three most important things as affecting the utilization of coal, namely, the influence of the amount of ash present, size of pieces of the fuel, and fuel loss occurring in smoke. If the Government could take Mr. Abbot's investigations as a pattern and follow them out to a more definite conclusion and continue the investigations relating to the distribution and location of boiler heating surface, or, in other words, the efficiency of boilers, it would be the best thing the boiler division could do, and afford practical data of great economic value. We have in Chicago two private companies, namely, the Chicago Edison Company and the Peabody Coal Company, each of which have made studies and researches with an expenditure of merely a fraction of the money used at St. Louis, and secured results of more practical value than has thus far been obtained by the fuel testing division, and this, I think, can be cited as evidence of the necessity for an improvement in the propaganda of this department of the U. S. Geological Survey work.

The most important feature shown by the diagrams, is the loss of heat due to unburned volatile matter, and Charts 1, 11, 12 and 13 illustrate the fact that such loss is an important and serious one in usual practice with bituminous coal. In Chart 13 is shown a rapidly increasing unaccounted for loss with increase in CO, this unaccounted for loss being that of unburned hydrocarbons, or, in other words, smoke. Chart 11 shows that the sum of CO_2, O and CO becomes less as furnace temperature increases; this is not due to the temperature, but to the fact that the quantity of air is less with higher temperature, and for this reason combustion was less complete with this condition, which was that of an intermittent fuel supply by hand. If the fuel supply had been uniform, and the furnace chamber of sufficient mixing capacity, the curve of total absorption would have been a straight horizontal line, and the curve of CO at zero for the full range of furnace temperature. Likewise Chart No. 13 shows that the unaccounted for loss increases with CO, the CO increases with furnace temperature, the unaccounted for loss is that of escaping hydrocarbons, not determined in the gas analysis. Therefore it is not correct as stated, that efficiency in steam making does not increase with furnace temperatures above 2200° to 2400° F. because the drop in efficiency is due to incomplete combustion which accompanied, but is not caused by the rise in temperature. If the feed of fuel is sufficiently uniform and the capacity of the furnace ample to ensure complete combustion, efficiency in steam generation will be at maximum with maximum furnace temperature, and this is an important fact which should not be overlooked. High furnace temperatures, of course, destroy brickwork faster than do lower temperatures, but the gain secured with high temperature, if accompanied by complete combustion, results in a fuel saving of such magnitude that the net gain due to it is very important.

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*Journal Western Society of Engineers, Vol. XI, page 529.

Chart 12 is unfortunate in its title, and I am surprised that the matter was so presented, because it has been thoroughly discussed in the Transactions of the American Society of Mechanical Engineers, Vol. XXVI, pp. 619 and 918, wherein the fact has been very clearly set forth that it can be of no advantage, even if full heat development is secured, unless it be done so at some useful temperature. The object of the fire is to heat something, and if its temperature is not sufficiently high to do so, there can be nothing gained in burning the coal, so we cannot consider furnace efficiency apart from temperature, yet this diagram appears to tell us that the lower the temperature at the fire (or its equivalent, the CO2), the higher the efficiency; or in other words, that the highest efficiency is secured with the lowest CO2. If it had been stated that the diagram shows the relation between completeness of combustion and CO2, it would have conveyed some correct meaning.

In reference to the inquiry relative to indications of the various CO2 instruments, under some conditions efficiency does not increase with the CO2; for example, with a hand fire it may be found that 7 or 8 per cent CO2 gives as high an efficiency as more CO2, due to the fact that as the air supply decreases, smoke increases, and for such condition there is a point where the lines will cross. Therefore in such cases it is necessary to secure means to produce completeness of combustion, and when this is done, efficiency will be at maximum with maximum CO2. To secure complete combustion may require that the fuel feeding method and the furnace be corrected. Thus if a boiler plant operates without making smoke, CO2 may be increased to the maximum with economy.

Referring to the statement concerning curve No. 1 relative to the behavior of coal high in "volatile" matter when used in a boiler apparatus of this character, attention should be called to the fact that the furnace employed in these tests is only a plain chamber, sufficient in those cases where there is a uniform feed of the coal by a stoker, but not so in the case of hand firing; because it has not sufficient auxiliary gas mixing devices to take care of the irregularity produced by hand firing, and under such conditions the "high volatile" coals are not only at a slight, but at a great disadvantage.

Referring to the inquiry regarding the theoretical, or in other words, the maximum possible percentage of CO_2 in combustion gases, I have taken coal of seams Nos. 6 and 7 of Illinois, which are the two most important producers, and have had CO_2 calculations made for them. Inasmuch as SO_2 in usual gas analysis is absorbed along with CO_2 and considered as being the same, two sets of values are tabulated, one including sulphur and the other excluding it, as follows:

	Illinois Coal Seams	
	No. 6	No. 7
CO_2 by volume	18.06	18.23
CO_2 by volume including SO_2	18.48	18.50
CO_2 by weight	25.54	25.81
CO_2 by weight including SO_2	26.44	26.38

Mr. Ray states that the authors see no reason why boilers cannot be constructed and properly operated with entire satisfaction, so as to produce about ten times as much steam per square foot of heating surface as is now done, and with no difficulty in obtaining dry steam. As far as dry steam is concerned, the matter is only one of proper design, but I would inquire how such larger capacity is to be had, and what proportion of the energy in the fuel will be necessary to cause the gases to flow through the narrow and extended gas passages which will be required, and by what means the motive power may be applied. Since the experiments of the Chicago Edison Co. a few years ago, it has been quite generally realized that it is desirable to employ baffling which will cause the gases to flow in contact with more of the boiler surface, than is usual in present accepted boiler design. This, however, requires smaller passages of greater length, and produces higher velocity of gases and greater resistance to their flow, so that with present available draft power, there is a limit to the amount of baffling, or in other words the resistance to the flow of gases, which will limit the capacity to an amount much less than ten times that which we now get with ordinary boilers. Speculation along this line leads to the idea of a furnace under a high pressure, discharging gases over the heating surface into a high vacuum and special means to induce the necessary high velocity in the circulating water, so that the heat may be absorbed as fast as supplied; this is at least a rather difficult mechanical proposition.

The Geological Survey I think should be highly commended for taking up these important subjects of boiler efficiency and capacity, and I hope that this branch of the work will receive the support and encouragement its great economic value justifies.

Mr. William Kent, Syracuse, (N. Y.) University, by letter. The definitions of efficiencies given, do not seem to correspond exactly with the definitions in the A. S. M. E. code, which are as follows:

72. Efficiency of a boiler. Heat absorbed by the boiler per pound of combustible divided by the heat value of one pound of combustible. (Combustible is defined in a foot note as the coal without moisture and ash but including all other substances. It is the same as what is called "coal dry and free from ash."

73. Efficiency of a Boiler including the Grate. Heat absorbed by the boiler per pound of dry coal divided by the heat value of one pound of coal.

These are the only two efficiencies described in the A. S. M. E. code. The other two efficiencies mentioned in the paper, furnace efficiency, the ratio of the heat actually developed in the furnace and the potential heat of combustible ascending from the grate; and true boiler efficiency, the ratio of the heat absorbed by the boiler to the heat which is available to it, would be interesting things to have if we could obtain them, but I do not see how it is possible to measure these efficiencies, for the reason that it can not be found out how much heat is actually developed in the furnace and how much is developed between the furnace and the chimney in the case of the coal giving a long flame and smoky gases.

In Table No. 3, it is interesting to note that coals from Alabama, Arkansas, Illinois, Indiana, Kentucky, Maryland, New Mexico, Ohio, Tennessee, Virginia, Washington and West Virginia all give efficiencies within the narrow range of 64.60 and 67.64 per cent, a difference of only 3.04 per cent. This would indicate that with most of the bituminous coals of this country not including lignites, nearly the same efficiency can be obtained with careful firing and with proper provision for burning the smoky gases. The average of these efficiencies is 65.45 per cent. This is 10 per cent lower than can be obtained with the very best conditions of firing, such as automatic stokers set in Dutch ovens. An efficiency of 75 per cent as compared with one of 65 per cent is equivalent to 131/3 per cent saving of fuel. This is the margin of possible saving between the average results obtained from bituminous coals in the St. Louis tests and the possible result under more favorable conditions. It is greatly to be desired that if these experiments are to be continued at Jamestown the best possible conditions be provided, such as an automatic stoker in which the thickness of the bed of fuel can be regulated as desired, and a large fire brick combustion chamber with baffling walls for causing a complete mixture of the gases before they are allowed to touch the cooling surface of the boiler. The Commission should not rest satisfied with tests which show 10 per cent efficiency less than what is possible with better appliances.

The upper line of the Chart No. 1 shows a great dropping off in the efficiency obtainable, when the volatile matter in the combustible is in excess of 40 per cent. This indicates that it is much more important with coals high in volatile matter to have the proper conditions for burning them than with coals low in volatile matter. The lower line on the chart indicates that the highest temperature in the furnace was obtained with a coal of about 34 per cent of volatile matter. This result can only be considered accidental. There is no reason, practical or theoretical, why coals low in volatile matter, even anthracite coals, should not give as high a temperature as a coal with 34 per cent of volatile matter, or any other percentage. The highest figure shown on the chart is only 2450 degrees. I have myself obtained 3300 degrees with Pittsburg coal, as shown by a Uehling & Steinbart pyrometer, and this was also confirmed by the fact that the platinum tube of the thermometer was softened and bent. The low temperatures given with the coals low in volatile matter in these St. Louis tests would indicate that too much air was passing through the furnace. The low temperatures with coals high in volatile matter may be caused either by too much air or by the moisture in the coal, which makes it impossible to obtain high temperatures.

The statement on page 292, that the rise of temperature with increase of volatile matter up to 30 per cent is due to increased rate of combustion, "for as the volatile matter increases the coal burns more rapidly and less air is used to burn one pound of combustible," is scarcely accurate. The rapidity of burning the coal and the quantity of air per pound of combustible are not necessary results from the quantity of volatile matter in the coal but are results of the thickness of bed and of the pressure of the draft. Any kind of coal can be burned as desired, either rapidly or slowly, if the draft conditions are provided for it; and any kind of coal can be burned with a large supply or a small supply, according to the thickness of bed, the obstruction which the bed offers to the passage of air, and the draft available. It would be well in future tests if the air could be supplied by positive blowers of the Root or other type, so that a definite and measured quantity of air could be sent through the bed of coal as desired, and not leave this quantity to be the accidental result of the two variables the draft pressure and the obstruction to the passage of air.

The relation of efficiency to percentage of ash in the coal shown in Chart No. 7 should be understood to be only the relation incidentally found in these tests and not the relation which may be found in other tests in which better provisions are made for burning the volatile matter in the highly volatile coals, and in which provision is made by shaking grates or otherwise, for getting rid of the ash without shaking the fire by opening the doors and shutting off the draft. There is no necessary relation between percentage of ash and efficiency but there may be accidental relation, as when high ash is combined with high moisture or high volatile matter or both, and when the ash is of such nature that it clinkers and chokes the draft and thus leads to imperfect combustion.

The relation between moisture in the coal and efficiency is also to some extent an accidental relation, due to the fact that coals with a large percentage of moisture and which are apt to generate water gas in a furnace, require more perfect provision for burning this gas than do coals cotaining low moisture and low volatile matter. In so far, however, as coals high in moisture tend to chill the fire and also in so far as the moisture generated leaves the chimney as superheated steam, taking heat away which ought to be given to the boiler, moisture will tend to cause low efficiency.

In regard to the classification of coals, there is still a large field for study of this subject and I doubt if it will ultimately be found that the relation between carbon and hydrogen in the dry coal is the best basis for classification. I have been studying the subject of classification of coals for some time but am not yet ready to present my views in detail on the subject, as further study is needed.

On page 306, it is stated, "It would reasonably be expected that when CO occurs, the flue gases contain other combustible gases which although they may be in unmeasured quantities may account for heat losses often double that indicated by CO." This is no doubt true and it is to be hoped that in future investigations an attempt will be made to account for this excess of loss. I would suggest that the excessive loss is probably due to the formation of water gas, CO+H, immediately after firing fresh coal, when there is insufficient air passing through the bed to burn the gas thus generated. The CO may be found, although with a considerable probable percentage of error, in the ordinary flue gas analysis, but the Hydrogen which escapes for say one minute after firing may not be found. It is doubtful if our methods of chemical analysis are sufficiently fine to determine with any approach to accuracy as small an amount as one per cent of Hydrogen in a mixture containing say 80 per cent Nitrogen, 10 per cent CO_2 and 10 per cent for the sum of other gases, but one per cent of Hydrogen in the chimney gases would account for a great loss of heat.

On page 309, it is said that the variation in temperature after each firing is due to the fact that the volatile matter is distilled off and that this distillation is a cooling process. There are two other causes of the fire being cooled at this time. 1. The checking of the air supply by the addition of fresh coal, much of which is fine, choking the air passages through the bed, causing the production of CO instead of CO_2, and thereby reducing the temperature; and the other is the decomposition of the moisture in the coal, which is probably a still greater cause for the reduction of temperature.

On page 309, it is stated that volatile matter is distilled off and burned in shorter time in the West Virginia coal than in the Ohio coal. This rapidity of distillation of different coals is one which should be further investigated. Some years ago I had to compare an Ohio coal with an Illinois coal. I found that on putting samples of both coals on the same iron plate heated by a Bunsen burner, the Illinois coal gave off great quantities of gas long before any gas was perceptible from the Ohio coal. In further investigations of the coals of the United States it might be well to determine at what temperature different coals began to give off their volatile matter and the length of time required to drive off all the volatile matter from different coals at different temperatures. This investigation may appeal strongly to some of our pure scientist friends, because the practical bearing of the results which may be obtained are somewhat remote.

I am not prepared to accept the mathematical equation shown on page 316 which shows the relation of heat transmitted to the several variables mentioned. I think we have too few experimental data available for any proper investigation of this subject. I am inclined to believe that the heat transmission varies as the square of the difference of temperature between the gases and the boiler plate and not directly as the difference, and that within the limits found in practice, it is independent of density, specific heat or velocity. Suppose a certain weight of gas has to pass at the rate of 20 ft. per sec. through a tube 2 in. in diameter, 20 ft. long, and that another equal quantity of gas with the same initial temperature has to pass through a 4 in. tube only 10 ft. long. The number of square feet of heating surface is the same in both tubes but the velocity is four times as great in the 2 in. tube than it is in the 4 in. tube. Have we any experimental proof which would show that the 4 in. tube is less efficient than a 1 in. tube for the same total quantity of heating surface and the same weight and initial temperature of the gases? The answer to this question, it seems to me, should be made from direct experiments on tubes with measured quantities of gas and not deduced from boiler experiments.

On the whole, I am greatly pleased with Professor Breckenridge's paper. It seems to me to be one of the best attempts at systematic study of the relation of causes and effects in boiler tests, that has ever been made. The making of hundreds of tests of boilers with different coals under different circumstances leads to no useful result whatever if these results can not be interpreted by some one with a scientific turn of mind who will tell us what the results mean and discover the relation of the several causes to the several effects. The great trouble with boiler tests is that a single result is due to a complex combination of causes and it is exceedingly difficult to make tests in which several variables may be eliminated and the effect of two or three variables be studied by themselves, without being complicated by a host of other causes, known or unknown.

I think the principal thing to be studied now in future boiler tests is the following: given the fact that any bituminous coal containing less than 10 per cent of moisture can be burned without smoke and so as to get 75 per cent efficiency, what are the best means for obtaining the conditions which will regularly give us these results in practice? The average results obtained in every day practice with bituminous coal mean that there is a loss of probably from 20 to 25 per cent of fuel which ought to and could be saved if we could find means of burning the fuel properly. Future tests should be directed to the discovery of these means. If the future boiler tests, to be made by the Geological Survey, should result in a saving of only a fraction of the coal which is now wasted under steam-boilers, the money contributed by Congress for these tests would be repaid a hundredfold, in a few years, by the saving of fuel which would result from the general adoption of improved methods of burning coal.

Mr. Ray: In explanation of some of the points brought up by Professor Kent, and referred to me by Professor Breckenridge, I will say, the numerical values of the efficiencies E1 and E2 defined in the paper correspond exactly with the values of the A. S. M. E. code, items 73 and 72, although the wording of the definitions given in the paper differs from that of the definitions in the code. The reason why these definitions were used is because in the analytical work of the steaming tests, three other efficiencies were used, and it was necessary to so word the definitions of the various efficiencies as to show the difference between them. In making these definitions an attempt was made to express by words exactly what the corresponding numerical values obtained by computation from the data of tests stand for. Inasmuch as we tried to study the boiler and furnace separately we could not call E1 the efficiency of a boiler and grate because it includes also the furnace. For that reason, we call it "The over all efficiency of steam generating apparatus," the latter including grate, furnace, and the boiler proper, considering as the boiler proper only the metalic vessel which absorbs heat and evaporates water. Although, in some instances, the furnace is constructed within the boiler it should be considered separately because its function is to evolve heat, which is exactly the opposite of the function of the boiler proper. The furnace wastes heat in three ways: (a) by not burning the fuel completely, thus not evolving all the heat in the coal, and (b) by evolving the heat at low temperature, thus making less of the heat available to the boiler, or (c) by radiating the heat after evolving it. The boiler wastes heat by not absorbing completely the heat which is available for it, and by radiating away the heat after absorbing it. The grate may waste heat by dropping combustible into the ash pit or removing it with the clinkers. Thus the over all efficiency of the steam generating apparatus can be reduced by heat being wasted in any one or all of the above ways. The fact that part of the heat absorbed by the boiler is radiated away justifies the use of the clause "and carried away in steam" in the definition. The accuracy of the definition of E1 given in the paper would not be improved if both of the heats used in the ratio were taken per pound of dry coal since this would only introduce the same factor into both of the heat values, leaving the ratio the same. The term "potential heat" was used because the heat which exists in the coal is in the potential form. E1 is the product of the individual efficiencies of grate, of furnace, and of boiler. E2 is based on the combustible which is either burned, gasified, or in any form rises from the grate. Numerically this combustible is equal to the combustible of the coal fired onto the grate minus the combustible which falls through the grate bars or is pulled out with clinkers. The phrase "combustible ascending from grate" was used because it includes all the combustible not lost in refuse. This efficiency leaves the grate out but takes in the furnace and boiler and is, therefore, rightly called the efficiency of the furnace and boiler. In the A. S. M. E. code this efficiency is called "the efficiency of the boiler." The code bases this efficiency on combustible and defines the latter in the foot-note as coal free from moisture and ash: however, it does not give any direction how the "combustible consumed" should be calculated whether by method (a) or by method (b).

It is true that the furnace efficiency E3 is difficult to obtain: nevertheless when there are 400 boiler trials made on the same apparatus and complete data, much can be done towards approximating it closely. Such approximations are of great help in locating the losses.

The true boiler efficiency is the only true measure of the ability of a boiler to absorb heat, and in research work its determination should be always striven for. All other boiler efficiencies are likely to blame the boiler for not absorbing the heat which is not available to it.

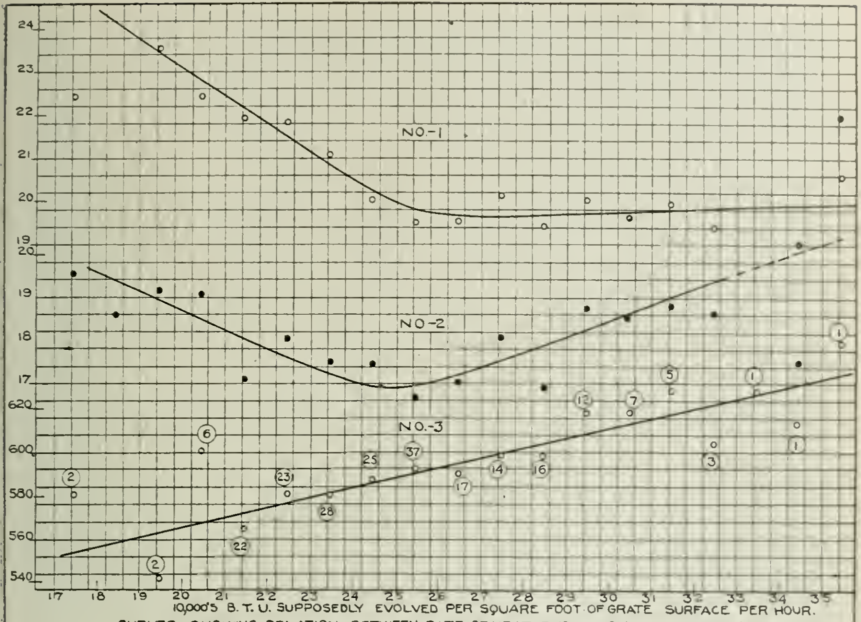
The indication of curve No. 2, Chart No. 1, is not accidental but rather characteristic of the Heine furnace and the fuels. No explanation is given with the chart how and where the temperatures were taken, and Prof. Kent was probably misled by thinking that the temperatures given were taken at a point in the furnace where they were highest. It should have been stated that the combustion chamber temperatures were obtained in the same way as explained in the second paragraph of the section on furnace temperature, that is, the temperatures were taken in the rear of the combustion chamber close to the opening into the tube chamber. This place which is about 15 feet from the grate, is in Fig. 4 indicated by the small circle. The temperature at this point is by no means the highest in the furnace; it was taken at this place because this was the temperature of the gases when they first come in contact with the heating surface of the boiler.

With coals high in fixed carbon most of the combustible is burned on the grate, and some of the heat is dissipated by radiation and conduction through the tile roof of the furnace before the gases reach the rear of the combustion chamber. With coals highly volatile the combustible is driven off as combustible gases and vapors which burn in the combustion chamber so that no time is left for the heat to dissipate before the temperature of the products of combustion is measured. Chart No. 14 supports these statements The highest furnace temperature with highly volatile coals was observed to be in the back of the bridge wall at the foot of the mixing structure and at the place indicated in Fig. 4 by the small circle. We have tests on record when the temperature at this place stayed for hours above 3,000° F. as indicated by the Wanner Optical Pyrometer. The fact that on two occasions an exposed platinum and platinum-rhodium thermo couple completely fused off when inserted into the furnace for 30 seconds is strong evidence of high tempratures obtained at this point. As the amount of volatile matter burned becomes less the point of highest temperature moves towards the grate.

Another reason given in the paper for the rise in combustion chamber temperature when the volatile matter increases up to 30 per cent. is that "as the volatile matter increases the coal burns more rapidly and less air is used per pound of combustible." First, the rapidity with which coals can be burned under similar condition such as can be provided with a hand fired furnace and natural draft is to a great extent depending on the percentage of fixed carbon and volatile matter in the combustible. We know, for instance, that we could not burn coke and Arkansas anthracite coal fast enough with all our available natural draft of about 0.7 inch of water to obtain more than 60 per cent capacity, while some of the Ohio and Illinois coals produced over capacity with a draft of 0.4 inch of water. Most of the West Virginia coals running 70 per cent in fixed carbon or over, burned so slowly that capacity could not be obtained with them. Of course, when we want to compare coals as to the rapidity with which each burns, nearly the same condition must be provided for all of them.

Chart No. 22 shows that the weight of dry gases per pound of combustible decreases with the rate of heat evolution until a certain point is reached and then it remains nearly constant. The rate of heat evolution is nearly parallel to the rate of combustion of combustible in coal. The heat supposedly evolved in the furnace is equal to the potential heat of one pound of combustible times number of pounds of combustible fired per hour minus the combustible lost in refuse, minus the heat lost in burning C to CO.

As to percentages of ash in coal affecting the efficiency it must be admitted that with any given apparatus and given conditions, coals containing more ash are always at a disadvantage. The same is true about moisture in coal.



CURVES SHOWING RELATION BETWEEN RATE OF HEAT EVOLUTION AND THE FOLLOWING:
NO.-1 POUNDS OF DRY CHIMNEY GASES PER POUND OF COMBUSTIBLE.
NO.-2 PERCENT LOSS UP STACK.
NO.-3 FLUE GAS TEMPERATURE (°F).
CLASSIFIED ON RATE OF HEAT EVOLUTION AS BASIS.

CHART NO. 22.
TESTS 126-358

I agree with Prof. Kent that the distillation of volatile matter from coal is a problem which should be very thoroughly investigated. Such investigations should be carried on with the object not only to determine the length of time taken by the distillation of the volatile matter from any given coal at any temperature, but also to determine the amount and the chemical composition of the volatile combustible leaving the coal at different temperatures, and when applying heat with varying rapidity. In other words, to study the desructive distillation of soft coals under different treatments such as heating it gradually and heating it suddenly. It seems to me that only in such investigations lies the solution of the smoke problem. Such investigation can better and cheaper be carried on in the laboratory with a small apparatus where all the conditions can be easily controlled than in a boiler furnace. Laboratory investigation should precede experiments in a boiler furnace designed according to the principles learned in the laboratory investigations. This is the problem of heat generation. Another problem in steam engineering, which should be investigated, is the problem of the transmission of heat, after it has been generated, from the gases into the boiler. This problem consists in the determination of the factors which influence the rate of the heat transmission both by taking the three ways of the heat transmission (radiation, convection and conduction) individually, and taking them together.

In my estimation, the most fruitful field of work of the Steam Engineering Division of the Technologic Branch of the Department of the Interior United States Geological Survey lies in the investigation of the above two problems.

Someone asked whether we had any curves showing the relation between the CO_2 content of gases and the temperature of gases leaving the boiler. We have. In general, they go up together; that is, high furnace temperature usually means high flue temperature; it may happen that this relation will be occasionally reversed under certain conditions, but the reversal can be accounted for by modification of the theory, which is treated of in the forthcoming publication mentioned.

In regard to the relation between the CO_2 content and the over-all efficiency: The over-all efficiency is inclined to go up with the higher CO_2 content. That, of course, is with our apparatus. Likewise the flue loss goes down with the higher CO_2 content. The unaccounted for item always goes up with CO_2, and I wish to emphasize the reason; the more CO_2 the less oxygen; the less oxygen, the less chance for the combustible gases to come in contact with it; the chance of any CO molecules getting burned is only partly as great with the high CO_2 content. The cutting down of oxygen is a very serious matter.

Several people have criticised our use of the term "furnace efficiency." We shall profit by this criticism and consider hereafter in this work that the "furnace efficiency" includes two things: First, completeness of combustion, and, second, high temperature. I realize that the use of the fuel under boilers is only one small use. There is an enormous amount used for metallurgical purposes. We will modify these definitions of "furnace efficiency" and put in some other curves we have to show both factors of furnace efficiency.

Someone said he did not think the "true boiler efficiency" (our efficiency E_4) was the right thing with which to compare boilers. In answer to that I will say it is the only thing, because, so far as we are able to find out from the actual tests on our two boilers, on some B. & W. data we have obtained from other parties, and on a number of locomotive tests, they all fit this theory of Perry's true boiler efficiency, and Mr. Perry states that this E_4 is nearly a constant for any one boiler. That is the constant that Mr. Bement has been talking about a great many years. The true boiler efficiency is probably fixed at a constant percentage for every boiler the moment it is finished in the shop, and so long as it is not rebaffled.

Mr. Saxe asked where one should seek for the highest CO_2. I should say, before the combustion is complete. Generally speaking, I do not know what the answer is.

Mr. Chauvet asked if anything was being done to determine the hydrocarbons. We are going to take up that matter now, indirectly, by calorimeter and other tests on flue gases, but not in the boiler division. We have already done a good deal of searching for them, but the results were obtained by mistaken methods and are not to be published.

In regard to the stratification of gases, we made a sampler once like that shown in Fig. 1, only instead of having *one* hole through which to draw gases, it had two, ½ inch apart. We never got two samples alike, during the same time, when using all precautions against errors.

Prof. Breckenridge: With reference to the rate of combustion which we found most economical with western coals, it was 20 to 24 pounds per sq. ft. of grate area in our apparatus.

The gas sampler shown was used directly over the fire, which would account for the fact that there was sometimes steam formed in it.

The question in regard to the relation of volatile carbon to the ash content in various coals is too long for me to answer at this time. It is answered in reports of the Chemical Division, and I would refer those particularly interested in that subject to those reports.

In regard to the matter of strata in gases, considerable work has been done by Mr. McGovney. It is a difficult thing to know how and where to get a gas sample. Many experiments have been made along that line, and it is certain it does make a difference where you get your sample. We are trying to devise means for mixing all the gases that come from the furnace, and pass them through such baffles as will enable us to get better samples.

The question of the amount of CO_2 must be considered with the point at which you take your gas sample. For a time we took our samples from the base of the stack. More recently we have taken our samples from the back of the combustion chamber. We find that is the best place to take gas samples, if you wish to discuss the problem of the burning of the coal on the grate.

We hope to have these tests of value. We have tried to do the work with accuracy, hoping the data would then be available for analysis and discussion, and I trust our hopes will be justified a little later.

Many of the questions which were asked at the meeting at which this paper was read have been answered in the discussion by Messrs. Ray and Kreisinger and need not be repeated here.

Mr. Bement refers to the expenditure of such a large sum of money for these investigations; it should not be forgotten that the work of the Boiler Division, as it was at one time called, has been but one part of the work of the Technologic Branch of the U. S. Geological Survey for which this money has been expended. Important work has been done by many other sections. In addition to the seven sections noted on the first page of this paper all of which come in the Fuel Testing Division there is a second large division known as the Structural Material Testing Division which has also been doing important work and helping to spend this money.

Of still greater significance, however, is the fact that it has been a necessary feature of this work that it should be carried on in connection with two great expositions. This feature of the work has made it very expensive as known by all who have had to do with the installation and operation of working exhibits in connection with World's Fairs.

It is much to be regretted that the publications of the reports of the various divisions have been so long delayed by the government. It is stated that the large amount of printing relating to the Panama Canal has been chiefly responsible for these delays.

When the results of all the work now completed and in progress are compiled and published there will, it is believed be ample justification for the expenditure of such large sums.

In his discussion of Chart No. 1 Mr. Bement apparently does not notice that the boiler setting referred to, does have a gas mixing baffle as shown in the drawing reproduced in Fig. 4. The writer desires to express for himself and his associates, appreciation of the many letters of commendation which have come to him in relation to the discussion of the tests presented in this paper. No one realizes more than he the unscientific methods which have of necessity been followed in much of this work. Still out of so much evidence he believes much of value may come.

Plans for future work have been more carefully worked out, discussed and approved by the National Advisory Board. When a permanent testing plant shall have been provided then will be possible many fundamental investigations, which have been delayed as impracticable under existing conditions.

SOME DETAILS OF CONCRETE CONSTRUCTION.

L. J. HOTCHKISS, M. W. S. E.

Presented March 6, 1907.

In concrete construction, more prehaps than in any other, development has far outrun the literature of the art. In reinforced work this is especially apparent, as new applications of this form of construction are so numerous that the ingenuity of the engineer is heavily taxed to provide economical methods of construction, and to see that no consideration of safety or good practice is overlooked. The author proposes to describe some of the methods used on recent work in the hope that the discussion may develop other methods of greater value.

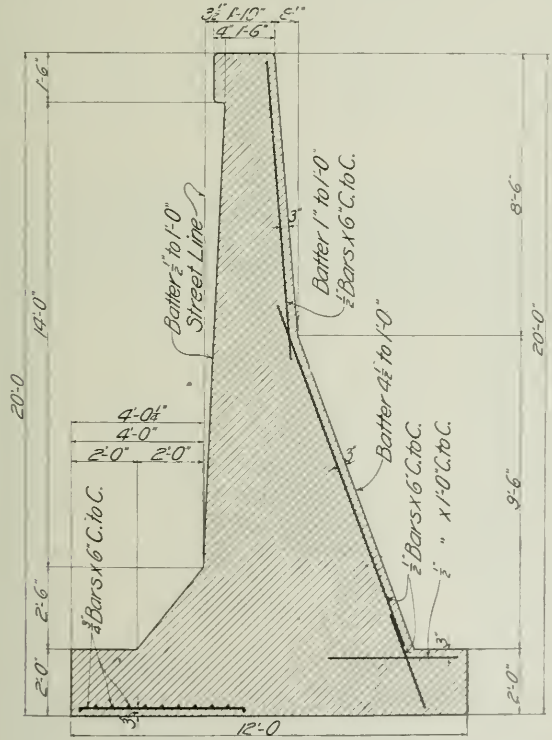


FIG. 1 TYPICAL CROSS SECTION OF TRACK ELEVATION. RETAINING WALL. C. B. & Q. RY.

In considering some of the features of concrete construction as carried out by the railroads, reference may be made to the track elevation work now going on in Chicago, in which a large amount of concrete, both plain and reinforced, is being used. In Fig. 1 is shown a typical cross section of the retaining walls being built by the C., B. & Q. Ry. This wall is but little more difficult to construct than a plain one, while the yardage is much less. Except where inclined walls are required for approaches to team tracks, the tops of all walls are at the same elevation, and that part of the cross section above the angle in the back of the wall is retained throughout. Changes in height are made entirely below this angle, the elevation of the footing varying in horizontal steps, thus maintaining the bearing surface normal to the direction of pressure, and facilitating the use of sectional forms, which will be illustrated later. Plain abutments are used in connection with these retaining walls, the footings having a reinforced projection in front to increase the bearing area. This type of abutments was used in preference to reinforced ones, because of difficulties in constructing the latter. All footings and the lower part of the abutments were built before any of the tracks were raised, the abutments being completed after the tracks had been elevated on temporary bridges. Rinforced abutments could not have been readily built in this manner.

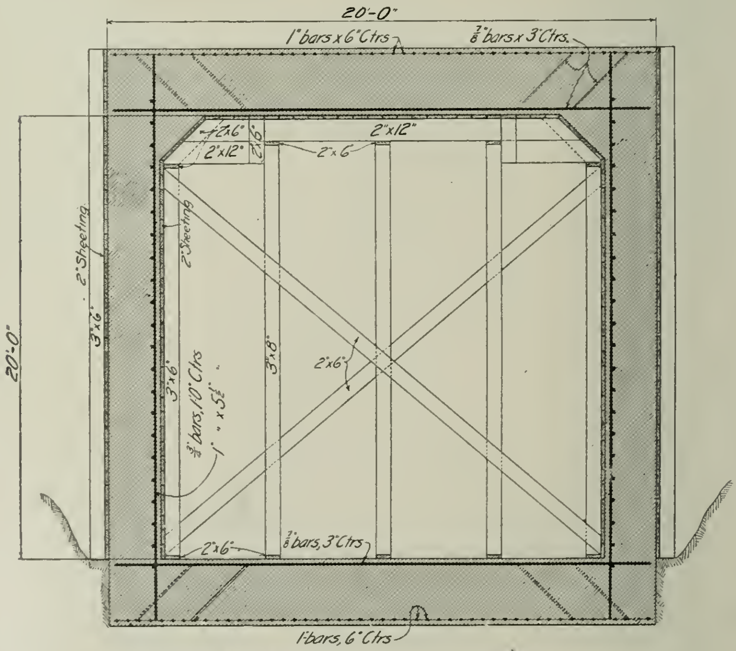


FIG. 2 SECTION OF FORMS AND BOX CULVERT.

Each track is to be carried over the subways on four spans of reinforced concrete deck girders, resting on the abutments and on three lines of steel columns and cross girders. The sidewalk girders are 10 ft. 9 in. long and 17 in. thick, and the street girders are 24 ft. 3 in. long and 33 in. thick. The girders are built in sections about 7 ft. wide, two sections being required for each track. There are to be 15 subways and the number of tracks carried will vary from 6 at Blue Island Avenue to 42 at Robey Street. Such a large number of girders, or "slabs" as they are called on the work, is required that a special yard was established for their manufacture.

This road is also doing a large amount of concrete construction outside of Chicago. Rectangular boxes form an important part of it. A cross section of one of them with the forms in place is shown in Fig. 2. They are used for culverts, cattle passes and subways, and are built to any length and under any embankment. They range in size from single 4 by 4 ft. to double 20 by 20 ft. and triple 16 by 20 ft. boxes. They have many advantages over arches, being far more simple both in design and construction. The form work is of the plainest kind. No piles are needed under them, and they may be placed on any kind of ground material, whether soft mud, quicksand or gravel. Where a rock foundation is available an arch is the cheaper form of construction. But in any location requiring piles the comparison is the other way. The massive abutments required to give stability to an arch, cover an area well outside the clear opening, and place upon the piles the weight of a mass of earth which, if a box culvert were used, would fall entirely outside the structure. The pits to be excavated for the arch exceed in breadth, depth and yardage, those required for a rectangular box. Where the material to be excavated is sand or soft mud, the single item of depth of foundation required, will make a large difference in the cost of sheeting and pumping. Where a structure is to be built under a track in service, the temporary opening required for a box culvert is but a few feet more than the clear span of the completed work, while for an arch the length of the temporary bridge must be increased to clear the abutments. Because of this difference a small box culvert can often be built between the bents of an existing pile bridge without in any way disturbing the latter, while if an arch were used one or more bents would have to be replaced by a temporary steel bridge. A large number of these boxes have been built by the C., B. & Q. Ry., and not one of them has failed to give satisfaction.

In Fig. 3 are shown the forms used on the retaining walls, previously referred to. They are a combination of continuous and sectional forms; the sectional part consisting of studs, coping and bottom forms for the face and sectional forms for the back of the wall. Ordinary sheeting is used between the coping and bottom forms, the back forming being entirely sectional. All sections are made in templates and delivered on the work in units, as shown in the figure. No attempt was made to use sectional forms on the face of the wall, except as mentioned, because the sections become battered and warped with use, do not fit closely together, and leave the wall rough when they are removed.

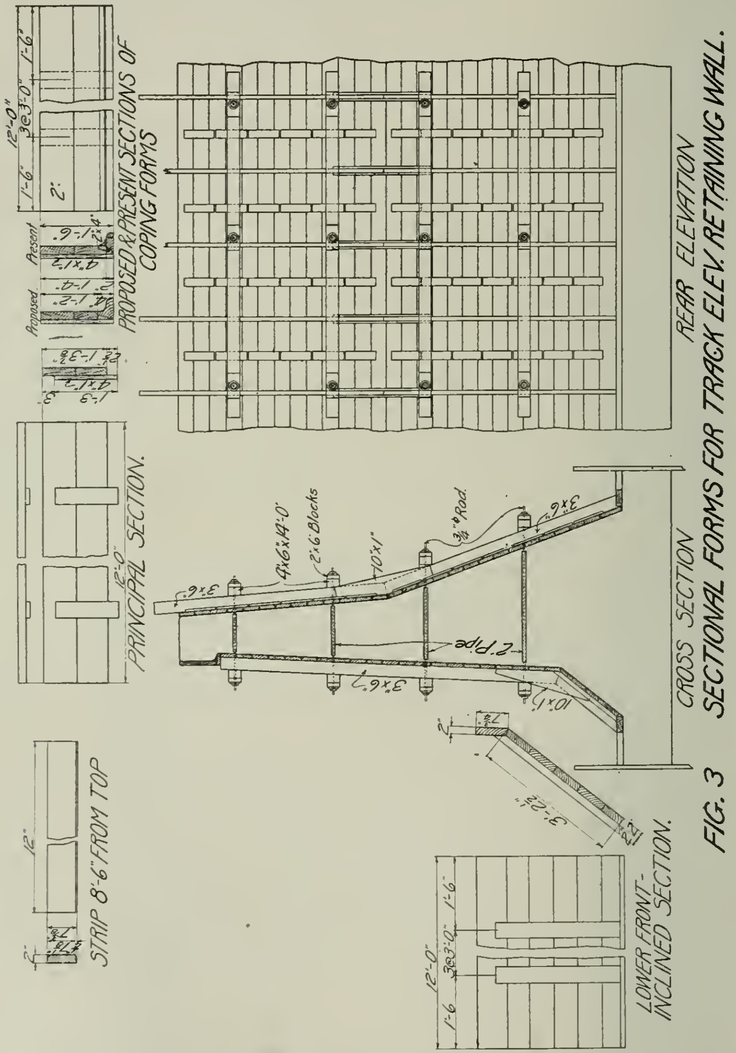


FIG. 3 SECTIONAL FORMS FOR TRACK ELEV. RETAINING WALL.

In Fig. 4 is shown the method of bracing and tying down the forms. The cross section of the wall is such that the wet gravel concrete used had a tendency to lift the forms off the footing. This did occur in one case, causing considerable trouble. The plan shown in the illustration was then adopted, the bars being placed in

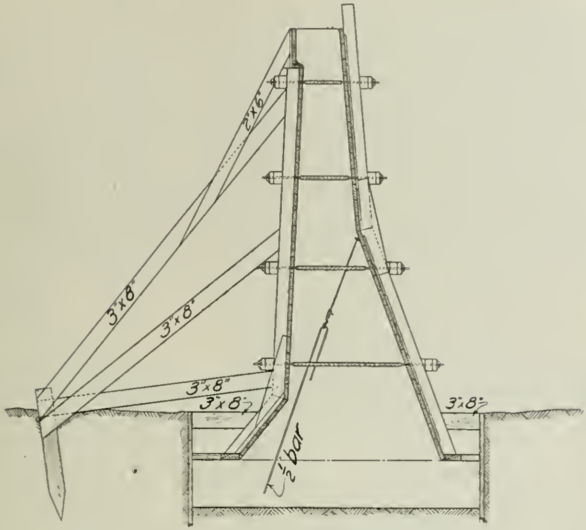


FIG. 4 FORM BRACING

the footing and the forms tied to them with wires. In building such walls it is difficult to keep them in perfect alignment. Small variations in the face of the wall are not noticeable, but any deflection of the coping shows at a glance. The method of bracing the coping form shown in Fig. 4 furnished an easy and effective way of lining up that form.

In Fig. 5 is shown the forms used for building the deck girders or slabs for the subways, this form being for one of the street slabs. These slabs are very heavy, weighing 35 tons each, and it was necessary that a good foundation be found for them. At Morton Park a large bed of cinders several feet deep was available. This was leveled off and the forms built there, the timbers supporting the forms being carefully tamped and leveled. Each side and each end form was complete in itself. They were set to templates laid on the floor of the box, as only ¼ in. clearance is allowed for each slab and were used many times. One hundred floors were provided, and when they were all filled with concrete the slabs first built were sufficiently seasoned to be piled up and thus permit using the floors again.

In Fig. 6 is shown one of the abutments which the C., B. & Q. Ry. built for a special subway at Forty-eighth avenue, Hawthorne. After the footing had been constructed, boxes having three sides and a roof were built between each pair of buttresses. These boxes formed back forms for the curtain wall, side forms for the buttresses and bottom forms for the bridge seats. They were very expensive on the first abutment, as all sheeting was placed horizontally and cut carefully to fit. On the second abutment most of the sheeting was placed vertically, and as little cutting as possible done. the result being a large saving in the cost of form work.

In fastening wall forms together the use of bolts or rods instead of wires increases the efficiency of the forms, and does not increase the cost. On the work described here pieces of scrap pipe were cut to fit loosely between the forms and the rods passed through them and removed after completion of the work. The ends of the pipes were stuffed with waste to keep the grout from filling them. Small blocks of wood placed between the form and the ends of the pipes have also been used for the same purpose, the blocks being later

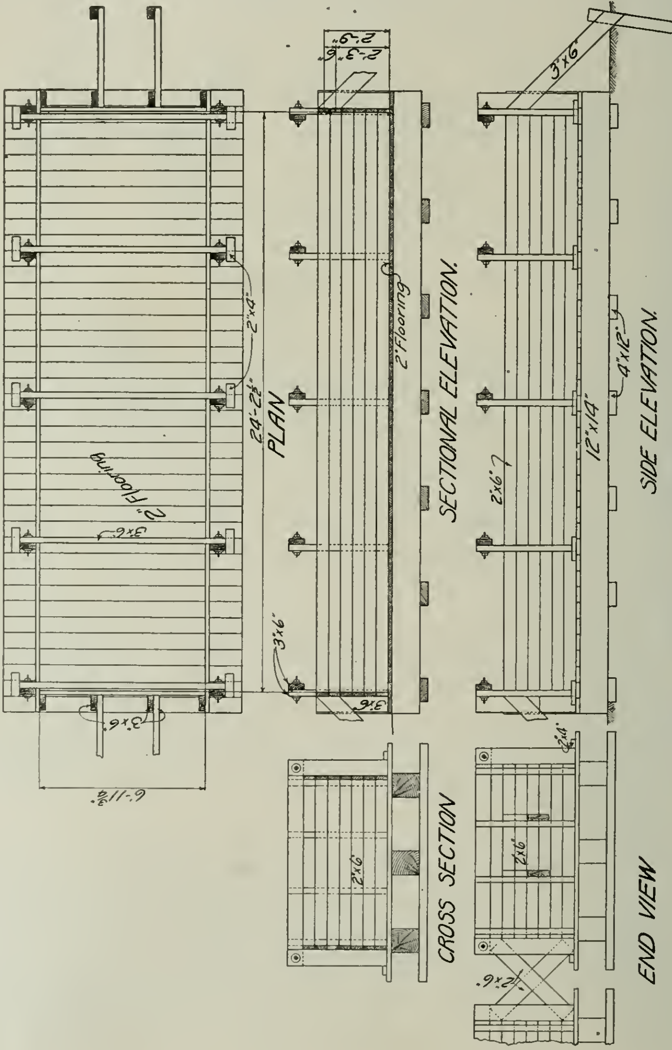


FIG.5 TRACK ELEVATION - SLAB FORMS.

removed and the holes filled with mortar. Neither plan is entirely effective, and the pipes sometimes fill with grout, making it difficult to pull out the rods. The rods and pipes cost but little more than wire and the labor of placing them is materially less. The wires always stretch a certain amount, and frequently break, permitting the forms to spread. If bolts are used the forms can be filled with wet concrete to a depth of 15 or 20 ft. without danger.

Forms should be coated with some substance to close the pores in the wood. The finish of the concrete is improved and the lumber is left in better shape to use again, as less concrete sticks to it.

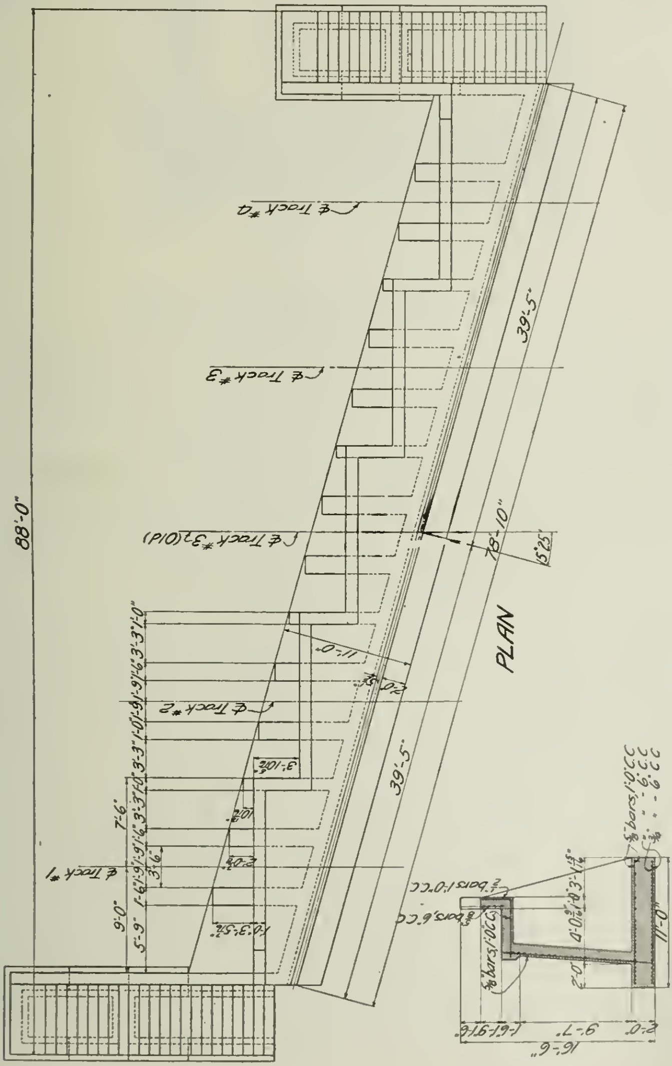


FIG. 6 - EAST ABUTMENT 48th AVE.

Soft soap thinned with water and applied with a whitewash brush or a broom works well for this purpose. Some drilling and lubricating compounds and black oil have also been used. They are greasy and do not dry quickly, and in this respect are better than soap.

The careful placing of bars is one of the most important features of reinforced concrete work, and one which is too frequently neglected because of the expense of doing it right. A method of placing them in the inverts of boxes, is shown in Fig. 7, which is both simple and effective. It applies equally well to wall footings. The stakes can be of any convenient size, 2 by 2 in. being sufficient. Their spacing depends upon the weight of bars to be carried. It need not be less than 6 ft. centers and can often be more. The longitudinal bars are secured to the stakes by wire nails bent over the bars. The bars are tied together at their intersections with small, soft wire, such as stove pipe wire. If a convenient clip applicable to all sizes of bars could be devised, it would be a welcome substitute for the wires, as this part of the work is slow and expensive, and must be thoroughly done, where the concrete is placed in large batches, especially if it is dropped several feet into the pit. Where a wet gravel concrete is used, the need of secure fastening for the bars is particularly great. Such a concrete flows easily and if bars are merely laid in place they will be swept aside as though they were chips. The vertical bars in walls may be carried on longitudinal timbers supported over the footing. They can be fastened with wire nails, and ordinarily only one line of supports is required, as the bars can be thrust into the concrete after the pit is partly filled, thus making the concrete assist in holding them. The longitudinal bars should be wired to the vertical ones if accurate spacing is desired. In thin walls this must be done before the forms are completed, because of the limited working space. In the roofs of boxes the bars can be supported in a manner similar to that used in inverts, the iron supports shown in Fig. 8 replacing the stakes. Small blocks of concrete cast with notches to retain the bars are also used for this purpose.

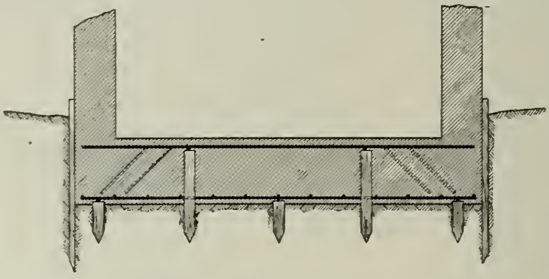
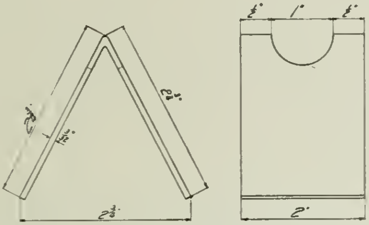


FIG. 7-METHOD OF SUPPORTING BARS.

For general use concrete mixed wet is better than a dry mixture. If good gravel is obtainable it is to be preferred to crushed stone. A wet gravel concrete can be handled much more cheaply than stone concrete, and gives as good results. It dumps easily from cars or buckets, can be placed in the forms with little labor, and requires no tamping. A derrick can serve a larger area from one position with such a mixture than if dry concrete is used, for the wet gravel concrete will flow in chutes placed at an angle so flat that dry concrete or even a wet stone concrete will not move in them.



FINISHED SUPPORT.

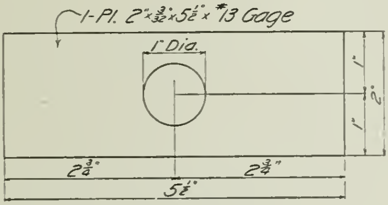


PLATE DEVELOPED

FIG. 8-CORRUGATED BAR SUPPORT.

In the construction of walls it is best to avoid longitudinal joints wherever possible. If a section of wall is partially filled, and the concrete allowed to stand for some time, it is difficult to remove all the "laitance," and in thin reinforced walls this work is difficult at any time. If it is not thoroughly done, an unsightly joint results, and one through which seepage will occur with consequent discoloration of the surface. Where the nature of the work will permit, vertical bulkheads can be built at convenient intervals, and the space between filled without stopping. More bolts must be used to tie the forms together than if the concrete were placed in layers, but otherwise the forms need not be heavier than would ordinarily be used. The concrete can be placed more economically, as less moving of equipment is required. The vertical joints are less conspicuous than horizontal ones. In plain walls they also serve as contraction joints, and if a triangular moulding is placed in them the resulting grooves relieve the monotony of the surface and conceal the opening of the joints from contraction of the wall. The use of vertical tenons in these joints is of little value, as the tenons quickly crack in the plane of the joints. A small percentage of longitudinal reinforcement will do the work of the tenons and also prevent contraction cracks.

Similarly, in building the inverts and roofs of boxes and footings for retaining walls, vertical bulkheads should be erected parallel to the tension rods, and the space between filled continuously. When quick setting cement is used in hot weather, care must be taken that these sections are not too long. In one case observed last summer, a section of the roof of a box equal to a day's work had been bulk-headed off. One end of the section was filled half full, and while the other end was being filled the concrete first placed became so hard a man could walk on it without making an impression. This made a joint in a horizontal plane, which should not be permitted in any beam.

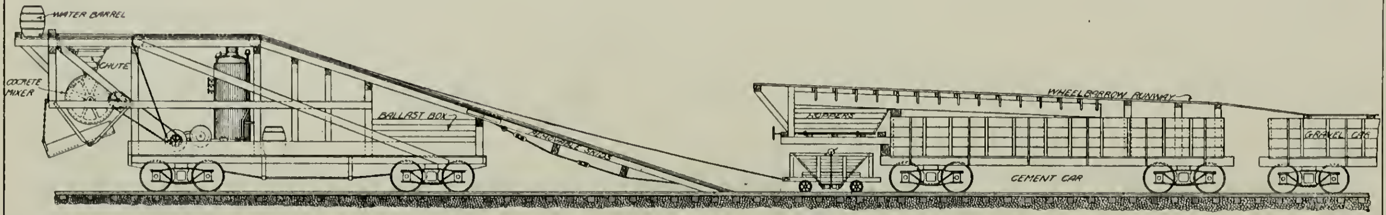
Occasions will arise, however, where a longitudinal joint in a wall is necessary, and where this is the case the thorough cleaning of the concrete is often neglected. The laitance is not all removed and dirt, shavings and sawdust are permitted to remain in the forms. This work cannot be left entirely to laborers but must have efficient supervision and inspection. The surface of the concrete should be scrubbed with wire brushes and water until every stone shows clearly, and the water used in the scrubbing should be flushed off and not left standing in the forms with the laitance in suspension, to be deposited on the concrete again as soon as the scrubbing gang has gone. Both time and expense can be saved if the cleaning is done before the concrete becomes hard. It can be done with shovels and a small amount of washing instead of the protracted scrubbing necessary later. The bond obtained in even the most carefully cleaned joint is of uncertain strength, and if the cleaning is poorly done, there is no bond at all.

For small jobs where it does not pay to install a power machine a hand power mixer mounted on a frame carried on two large wheels is used by the C., B. & Q. Ry. This machine is turned by a crank driving a sprocket chain. It is charged at the material piles, turned and hauled to the work to be discharged into the forms, and is fairly satisfactory. It requires much turning and the men are apt to become careless and dump it before mixing is completed, but, with careful supervision, good work can be secured. The mixer is at least as efficient as hand work, is more convenient and easier on the men.

On many railroad jobs local conditions are such that a power mixer of large capacity cannot be worked to its limit. Difficulties in supplying it with material, or in taking away the concrete, reduce its output to that of a much smaller machine. The latter is cheaper in first cost, in installation and in operation. On the other hand, if the yardage is sufficient to justify the installation of equipment for handling the output of a large mixer, it is better than a small one, for the increase in plant charges is not in proportion to the increase in amount of concrete handled. Again, it may occur on a comparatively small job that the concrete must be taken a long distance from the mixer, that a large batch can be moved as quickly and easily as a small one and the time consumed in doing it is sufficient for the charging and turning of a large machine before the concrete car or bucket returns. Here the large mixer, while it may stand idle part of the time, is still econmical. The use of continuous mixers is undesirable unless there be used with them a reliable measuring and feeding device. Without such a device the concrete is lacking in uniformity both as to proportion and consistency. One outfit, observed recently on street paving, serves to illustrate this. Stone was piled on one side of the machine and sand on the other. Three men shovelled sand into it while six others supplied it with stone and yet another put in cement from time to time. The concrete as dumped on the ground was sometimes wet and sometimes dry. Part of it was thoroughly mixed and part was but slightly mixed. This is doubtless an extreme case but similar ones are numerous and show the lack of reliability of such machines when used without proper appliance for proportioning the mixture.

The varying requirements in the way of equipment is well shown in the construction of some of the concrete boxes to which reference has been made. They are often located under a high, short trestle at the end of which the material must be unloaded on the side of the enbankment. The conditions at such a job recently built, permitted the installation of a convenient plant. Old bridge timbers were available for building a platform along each side of the embankment about 8 ft. below the top of ties. A track for a material car was built on each platform before gravel was unloaded on it. Each track extended out over a mixer located on the end of the embankment and bottom dump cars, operated by hand, discharged directly into the mixers. The latter discharged into concrete cars running on a slightly inclined track up which they were pulled by the mixer engine to a point over the concrete "box" to be built where the loads were dropped into other cars, on a track running the length of the "box" and supported above it, on the forms.

Another long box culvert, also just completed, required a very different lay out. It was located in a flat valley traversed by a meandering creek and about 600 ft. from the present track. Gravel was unloaded from this track on the side of the embankment at the foot of which a large platform had been built with its outer edge raised enough to clear two tracks carrying 5 yd. side dump cars. Gravel was loaded into these cars through holes in the platform by means of teams and drag scrapers and the cars drawn to a point near the work with a cable operated by the mixer engine. The gravel was dumped at the foot of an inclined platform leading to a hopper elevated sufficiently to let a 1½ cu. yd. bottom dump car pass under it. A team, a cable, and a drag scraper, delivered the gravel through the hopper into the material car, cement being put



CONCRETE MIXING OUTFIT FOR TRACK ELEVATION. C.B. & Q. RY.
FIG. 9.

in by hand at the same time. The mixer engine pulled the material car up an inclined track from which the mixer was charged. The concrete car into which the mixer discharged was drawn up a steep incline leading to a track which extended the full length of the culvert and was supported above it on the forms.

At Galesburg a double 13 ft. by 12½ ft. concrete box to carry a street under a new yard was built entirely below the level of the natural ground. For this work an old steam shovel was available. It was transformed into a derrick with a 40 ft. boom and operated on a track parallel to the work. The mixer discharged concrete into cylindrical bottom-dump buckets seated on push cars. The latter were pushed by hand to where the derrick could reach them and the buckets swung out over the box to drop their loads onto chutes. The concrete was thus placed in any desired part of the work with but little hand labor.

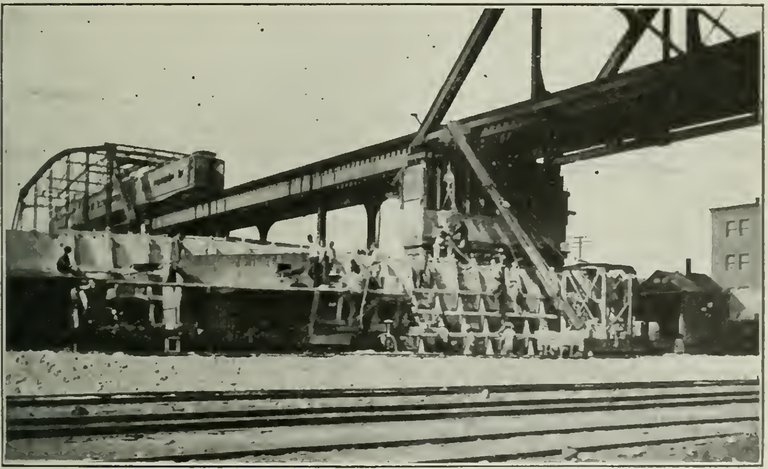


Fig. 10.

The work on the Chicago track elevation required outfits easily moved from place to place and several somewhat similar schemes have been used. In Fig. 9 is shown one of the C. B. & Q. Ry. outfits. The cement car is located ahead of the gravel cars and overhanging its forward end carries two hoppers of 1½ cu. yd. capacity each. The two hoppers enable the wheel-barrow men to work continuously, the material car being charged alternately from either hopper. The material car is pulled up the incline to the charging platform by the mixer engine. The mixer is arranged to discharge into a chute, a bucket or a concrete car.

In Fig. 10 is shown an outfit used by the C. & N. W. Ry. Only part of the material cars are shown, but the material is brought forward by wheel-barrows on runways laid on top of the cars and dumped directly into the mixer. By means of a hopper with a gate the concrete was discharged into wheel-barrows when desired.

The equipment used by the contractor on the I. C. R. R. retaining walls at Grant Park is shown in Fig. 11. The light derrick travels back and forth on a track laid on two flat cars thus distributing the concrete uniformly over a considerable section of wall.

All of these outfits have one serious fault, the use of wheel-barrows for bringing the material to the mixer. The wheel-barrows are so high above the bottom of the car that loading them is a matter of difficulty and the wheelers and shovelers are entirely unreliable. The contractor on the Chicago Junction Ry. has gotten up a scheme which does away with the wheel-barrows, and is a long step in the right direction. Two narrow gauge tracks are carried over the tops of the material cars, and connect on the mixer car into a single track which extends over a hopper above and back of the mixer. Two long, low steel dump cars of about 1 cu. yd. capacity are operated, one on each track. A cable from the mixer engine pulls a car up to the hopper where it is dumped and automatically returns to its normal position. The track on the mixer car is inclined and gives the empty car sufficient momentum to return it for reloading. This car seems to be open to one objection. As it travels along the outer edge of the material cars it can only be loaded from one side. Not more than four men can shovel into it at a time. The capacity of the plant is therefore limited to the output of eight shovelers but the contractor says that with it he was able to handle at least as much concrete as local conditions would permit him to place with any other outfit. Even if no increase in output or reduction in expense results, the decrease in the number of men required is a distinct improvement, especially in view of the prevailing scarcity of labor.

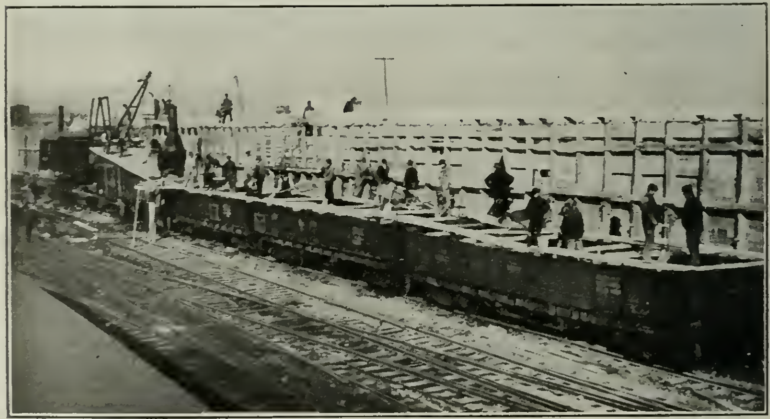


Fig. 11.

Spading the face of the concrete to secure a finish gives good result if the work is carefully done and no washing of the wall with grout should be required. In the writer's opinion this method is superior to any form of mortar facing. It is easier and cheaper, is equally effective and the face does not check or crack. A mortar finish does both, in the course of time, permitting seepage and discoloration of the face of the concrete.

For doing the spading, a common garden hoe, straightened out until the blade is nearly in line with the handle, is an excellent tool. For reinforced work where the spading must be done in a space of two or three inches, this tool is particularly useful. On high reinforced walls which must be spaded from the top, long handles are required. It is well to have these tools with different lengths of handle, the shorter ones being used near the top. Reinforced walls 20 ft. high have been finished in this manner and no other treatment was needed.

It is often necessary to build walls with the top sloping steeply as in the case of wing walls for abutments and culverts. Where wet concrete is used covered forms must be built for such walls, to keep the concrete from flowing out at the bottom of the slope. The cover boards can be removed as soon as the concrete has set so it will stand, and then the surface finished with a trowel. In hot weather this work can sometimes be commenced at the bottom of the slope while concrete is still being placed at the top. In chilly weather the wall can stand over night and the cover boards be removed in the morning and the surface finished.

The C. B. & Q. Ry. specifications require that exposed edges be finished to a curve of small radius. For this purpose cove moulding is often used. It works well for vertical edges and for the lower edges of horizontal beams. If used for the tops of walls the concrete in setting shrinks away from the moulding leaving a rough surface. A better finish can be obtained by working the green concrete with a curved edging tool such as used in sidewalk construction.

The amount of concrete placed during the winter months is constantly increasing and this work can be done with entire safety, if proper care be taken in heating the materials and keeping the concrete warm in the forms. For thin reinforced walls, it is not safe to rely on heating the water alone or even the water and sand, but the stone also must be heated and the concrete when it goes into the forms should be steaming hot. For mass walls the stone need not be heated except in very cold weather. Where concrete is mixed in small quantities the water can be heated by a wood fire and if a wood fire be kept burning over night on top of the piles of stone and sand a considerable quantity can be heated. The fire can be kept going during the day and moved back on the pile as the heated material is used. This plan requires a quantity of fuel which in most cases is prohibitive and is not sufficient to supply a power mixer. For general use steam is far better. A convenient method is to build a long wooden box 8 or 10 inches square with numerous holes bored in its sides. This is laid on the ground, connected with a steam pipe and covered with sand, stone or gravel. The steam escaping through the holes in the box, will heat over night, a pile of sand, or sand and gravel 8 or 10 feet high. Perforated pipes can be substituted for boxes. Material can be heated more rapidly if the steam be allowed to escape in the pile than if it is confined in pipes which are not perforated. Crushed stone requires much more heat than sand or sand and gravel mixed because of the greater volume of air spaces. In many cases material which has already been unloaded must be heated. The expense of putting steam boxes or pipes under it is considrable. To avoid this one or more steam jets may be used, the end of the jet pipe being pushed several feet into the pile of material. If the jets are connected up with steam hose they are easily moved from place to place. It is difficult to heat stone in this way except in moderate weather. The writer recently tried with a single jet to heat a pile of stone when the thermometer showed 25 degrees below zero, and was unable to supply a single small gang mixing by hand, although another jet heated an abundance of sand. Concrete cannot be placed in such weather except at an expense for heating which is only justified in extreme cases.

On mass work and at such temperatures as are met with in this latitude it is not usually necessary to protect concrete which has been placed hot except in the top of the form. This can be done by covering the top of the form with canvas and running a jet of steam under it. If canvas is not available boards and straw or manure answer the purpose. If heat is kept on for thirty-six hours after completion, this is sufficient, except in unusually cold weather. The above treatment is all that is required for reinforced retaining walls of ordinary height. But where box culverts or arches carrying heavy loads must be placed in service as soon as possible, the only safe way is to keep the main part of the structure warm until the concrete is thoroughly hardened. Forms for these structures can be closed at the ends and stoves or salamanders kept going inside, or steam heat may be used. The outside may be covered with canvas or boards and straw and steam jets run underneath. After the concrete has set enough to permit the removal of the outer forms of box culverts, fires may be built near the side walls and the concrete seasoned rapidly. Where structures need not be loaded until after the arrival of warm weather, heat may be applied for thirty-six hours, and the centering left in place until the concrete has hardened. Careful inspection of winter concrete should be made before loads are applied. In this connection it may be noted that concrete which has been partly seasoned and then frozen, closely resembles thoroughly seasoned concrete. Pieces broken off with a smooth fracture through all the stones and showing no frost marks, yet when thawed out, can be broken with the hands.

In conclusion, it cannot be too strongly urged that all details of concrete work be carefully done, as the simplicity of most of the operations leads to carelessness.

DISCUSSION.

Mr. T. L. Condron, M.W.S.E.: With reference to the building of walls with expansion joints, there is no objection to such joints in the average retaining wall such as described, but occasionally a wall is to be built in which it is not proper to have expansion joints, particularly where walls are to withstand water pressure. It is possible to build walls that will be water tight, and therefore, without expansion joints. The speaker has designed walls where this condition was to be met. These walls are each 350 feet long, and are partition walls in reservoirs, or filter beds.

To take care of shrinkage stresses, these walls are reinforced longitudinally with corrugated steel bars to the extent of 1/300 of the cross section of the concrete. The walls were so built that they were supported at the top as well as at the bottom, and formed a slab 14 ft. high, 350 ft. long, and 12 in. thick. No special means were taken to waterproof them. A wet mixture of gravel concrete was used, of proportions about 1:2-½:5. cement, sand and gravel. The walls, of course, could not be completed in a single day's operation, and where the work stopped, the concrete was stopped off on a slope, and the next morning when work was resumed the slope was thoroughly washed down but not brushed, and the new concrete placed on it, first putting on a cement grout and then dumping in the concrete. All of the concrete was dumped from the top of the 14 ft. wall, and when the work was finished you could see the end of each day's work.

The walls constantly withstand water pressure, and I have walked along the length of two of the three walls, when there was a head of ten feet of water on the opposite side of each, and there was no sign of leakage except, that in a very few places a little leakage occurred where wires passed through to hold the form. I simply mention this as a sample of what can be done in a case where it is absolutely essential not to provide for an expansion joint.

The cross section of the wall shown by Mr. Hotchkiss is not unlike one which was designed something over two years ago and built just outside the city of Indianapolis. Up to that time no other wall of that shape had been built, or at least described, so far as I know. That particular wall in Indianapolis was 300 ft. long and had the reinforcing in the back as shown in Mr. Hotschkiss' paper, Fig. 1; it also had longitudinal reinforcing on the face.

The question of holding the bars in position during construction of reinforced concrete work cannot be too forcibly brought out, and the means of doing this should be carefully studied for each case.

Mr. Hotchkiss refers to a cement block which he did not illustrate, but which has been used very successfully in beam boxes in some of the work I have designed. We have even used them where we had two layers of reinforcement in a beam, using two sets of blocks. These cement blocks are generally strengthened by a wire embedded in them, and such blocks remain in the finished concrete, and do not show. They are much more satisfactory than attempting to support the bars by wires suspended from the top, as is frequently done.

Mr. O. P. Chamberlain, M.W.S.E.: I have been much interested in Mr. Hitchkiss' paper; he has gone very thoroughly into the subject of handling reinforced concrete work for retaining walls and beams in bridge work. I might add a little something, however, along the line of retaining walls. That is, in regard to whether the reinforced retaining wall is more economical in construction than the solid wall.

I took time recently to sketch a solid retaining wall and compared the amount of concrete in a wall of that kind with that in a wall as shown in the illustration on the first page of this paper. The amount of concrete per lin. ft. of wall, taking the section shown in Fig. 1, is 3.2 cu. yds. Taking this section for solid wall, it is 3.33 cu. yds. The section shown in this paper is the section used by the C. B. & Q. Ry. and is similar to many other sections for retaining walls. While it is very light at the top—and properly so—it is extremely heavy toward the base. Taking the cost of concrete in the two walls and adding the amount chargeable in the C. B. & Q. wall, to reinforcement, the section shown in the drawing would, I think, be a little more expensive per lin. ft. of wall, than the solid wall.

There are also some other features in which I think the solid wall has the advantage. In building a solid wall most of us would undoubtedly carry the back of the wall up in steps, which would give us considerable advantage in stability, the weight of the back filling being partially carried as a direct load on the wall. I simply wish to call attention to this matter. It is not an undisputed fact that the reinforced retaining wall is cheaper or more economical than a solid wall. You will find that here in Chicago many of the retaining walls being built are in accordance with the old solid construction, and I think a great many engineers favor such construction.

There is another statement which I think is, in part, questionable, and that is the one in regard to the use of gravel concrete, referred to by Mr. Hotchkiss who says that "for *general use,* concrete mixed wet is better than a dry mixture." Of course that is true. The wet concrete is easier and cheaper to handle. Our tests show that this produces better concrete than the old method of mixing it almost dry and tamping it. But to the following statement—"If good gravel is obtainable, it is to be preferred to crushed stone"—I take exception. I think the use of a concrete of crushed stone and gravel and sharp sand is admittedly better than either gravel alone with sand and cement, or crushed stone with sand and cement. In my own practice I have used all three. I have used gravel concrete, which was made from pit gravel mixed with pit sand, and cement, which produced a very good concrete. I have also used stone and sand, and stone and sreenings, with cement, but I think the best concrete must contain crushed stone; in fact, I am quite certain that tests made by Robert W. Hunt & Co. show that gravel and stone and sand with cement in proper proportions, give a concrete that has the greatest tensile strength. This is something I think it worth while to call attention to.

So far as the ease of handling concrete with the Smith mixer is concerned, in the handling of wet concrete I can see little difference, whether it be made of crushed stone or gravel. It is true that the wet mixture of concrete is much more easily and economically handled than the comparatively dry mixture.

Mr. W. A. Hoyt, M.W.S.E.: In regard to the retaining wall, the first thought I had in looking at the section was the inadequacy of the reinforcement. Perhaps it is presumptious for me to make this criticism, yet the former speaker has alluded to the comparative cost of a reinforced wall and a solid concrete wall. I wish the author had given us some of the data he used in arriving at his conclusion. He says ½ in. steel bars were used, but does not say whether they were round or square.

It seems to me that such bars are rather small to reinforce a heavy concrete wall. I therefore consider this wall neither a reinforced nor plain wall. I figured out roughly, the resisting moment of the concrete section he uses at the base, and using that section you would need a plate of steel about 1⅛ in. thick over the entire back, to develop the strength of the concrete. It seems to me he could cut down the section a great deal and use much more steel, and get thereby a much cheaper wall. I wish he would give us the data he used in arriving at this result.

Mr. O. E. Strehlow, M.W.S.E.: I think that all the old questions that are brought out by Mr. Hotchkiss are pretty well understood; viz., wet concrete, gravel concrete, "spade finish," etc. But it has not been brought out that most of the railroad companies in Chicago have not yet adopted the material and methods on their work. The greatest number are using crushed stone; some are using moderately wet concrete, and others a mortar face. My opinion is that the gravel concrete as mixed by the C. B. & Q. Ry. is about the right kind, it being mixed very wet so that it will almost flow; it is so desired especially for reinforced work. When vertical bars are used they are jarred by the concrete dropping into the forms and they may be disturbed in other ways. The wet concrete, which also sets much more slowly, will adjust itself around those bars a foot or two feet down, after the concrete is placed, which would not be the case with ordinary dry concrete. I think that not only is the cost of placing wet concrete less than dry concrete, but that compressive tests on 6 in. cubes mixed very wet show that after three months' seasoning the strength in compression was about 15 per cent greater, while in seven days' time it was about 50 per cent less; in 30 days' time it was probably 25 per cent less than dry concrete.

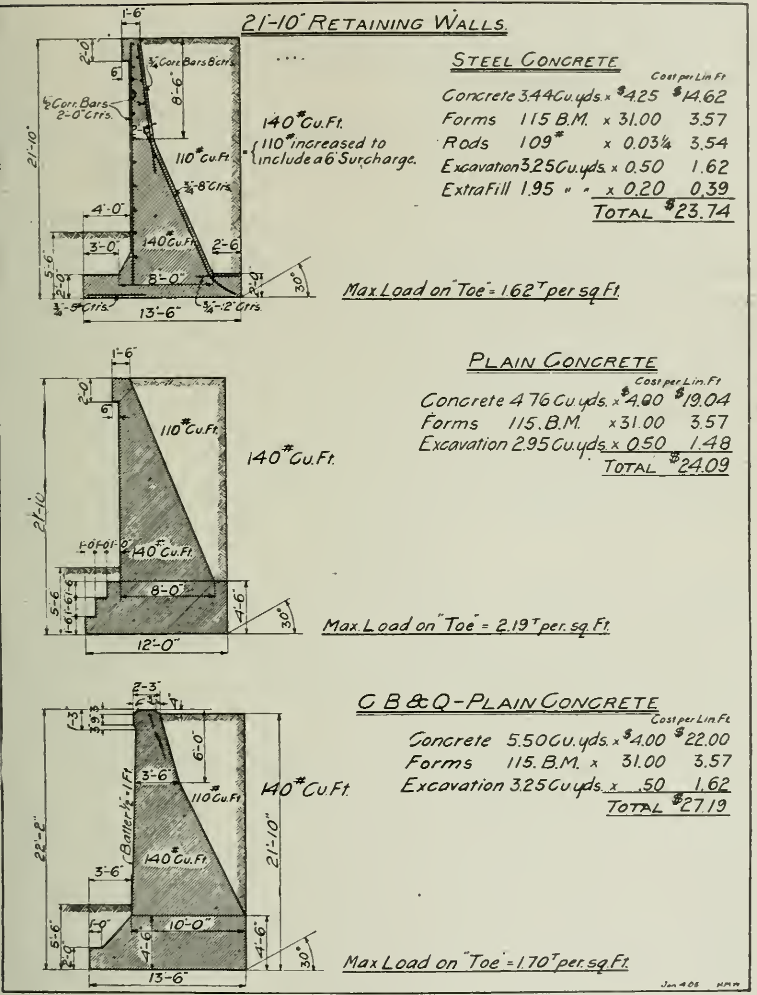
Sane engineers base their opinion on short time tensile tests of mortar instead of ninety-day compression tests of concrete, which represents conditions in actual work. The concrete in reinforced work is not intended to take care of the tension.

Mr. W. B. Ewing, M.W.S.E.: I notice that the base or footing extends a considerable distance outside of the wall. In this city real estate is considered rather a valuable possession.

This base either extends outside the right of way or else a space of 8 ft. on each side of the right of way is lost. It seems to me it would be better to design a wall where the toe extended along inside the right of way, or else get permission to allow the footings to extend outside the line of the right of way and give the maximum area. Would it not be better, instead of supplementing the bars at the angle where the weakest part of the wall begins, to extend that top bar down some three feet below?

Prof. A. N. Talbot, M.W.S.E. (by letter): The writer hopes Mr. Hotchkiss will explain more fully the meaning and purpose of the reinforcement used in the retaining wall and the box culvert illustrated in his paper. For ordinary conditions of loading, it would seem that the reinforcement is not well placed or that it was not intended to use the steel entirely for reinforcement against load stresses. The writer calls attention to this because so often designs are given for reinforced concrete structures in which the reinforcement seems not to follow the lines which an analysis of the stresses would indicate should be used. He desires to ask how much stress is transmitted by the lap of the bars and what resists the stresses set up by the angle which the two sets make with the others in the retaining wall.

Mr. Condron: Referring to Mr. Chamberlain's remarks—I have a diagram, Fig. 12, which shows a comparison between three forms of retaining walls, one of which is similar in section to the wall described by Mr. Hotchkiss. The reinforced concrete wall shown in this sketch has a height of 21 ft. 10 in., and the section of the concrete is 3.44 cu. yds. per lin. ft. of wall (estimated cost, $23.74). The plain concrete wall of equal stability has 5.50 cu. yds. per lin. ft. (estimated cost, $27.19). The other plain concrete wall has 4.76 cu. yds per lin. ft. (estimated cost, $24.09), but the pressure on the toe of the latter is 29 per cent greater than the pressure on the toe



STEEL CONCRETE

			Cost per Lin Ft
Concrete	3.44 Cu. yds.	x $4.25	$14.62
Forms	115 B.M.	x 31.00	3.57
Rods	109#	x 0.03¼	3.54
Excavation	3.25 Cu. yds.	x 0.50	1.62
Extra Fill	1.95 " "	x 0.20	0.39
		TOTAL	$23.74

PLAIN CONCRETE

			Cost per Lin. Ft
Concrete	4.76 Cu. yds.	x $4.00	$19.04
Forms	115. B.M.	x 31.00	3.57
Excavation	2.95 Cu. yds.	x 0.50	1.48
		TOTAL	$24.09

C B & Q - PLAIN CONCRETE

			Cost per Lin. Ft
Concrete	5.50 Cu. yds.	x $4.00	$22.00
Forms	115. B.M.	x 31.00	3.57
Excavation	3.25 Cu. yds.	x .50	1.62
		TOTAL	$27.19

Fig. 12.

of the reinforced concrete wall. The fact of the matter is, there are miles of retaining walls built in Chicago, in which the pressure on the toe (by the usual methods for determining the same) is very excessive and the pressure on the back or heel of the wall is a negative quantity. It is not surprising that some of these walls, having twice the cross section referred to in the blue print tip out at the top under load. I believe everybody familiar with the retaining walls built in Chicago will agree that most of them do go out at the top after they are built. That point has been studied by many engineers, and it has been very difficult to get a monolithic wall that would not have excessive pressure on the toe and a negative pressure on the heel; in other words, the center of pressure, is usually too far from the center of the base.

The ideal way is to have the pressure fall not in the middle third but at the center of the base. It is almost impossible to secure this with a monolithic wall, but it can be secured with a reinforced concrete wall.

I think the author of the paper, in describing the reinforcing for this wall, has brought out the point that it is not a reinforced concrete cantilever beam intended to balance the full value of the concrete in compression by the tension in the steel, but that only enough steel is used to take care of the tensile stress in the back of the wall. I quite agree with Mr. Hoyt that it is open to discussion if a wall cannot be more economically built, by reducing the mass of concrete and increasing the amount of reinforcement.

Mr. Allen, M.W.S.E.: It would be interesting if Mr. Hotchkiss could give us a description of the C. B. & Q. track elevation, which I understand consists of reinforced concrete girders, on steel columns and cross girders.

CLOSURE.

Mr. L. J. Hotchkiss: The points brought out by Mr. Chamberlain, concerning the comparative cost of plain and reinforced walls, have been so fully discussed by Mr. Condron that I cannot add anything along that line. But I do not agree with Mr. Chamberlain when he says that a wall with the back carried up in steps has more stability than if the back is sloping, because it carries more of the weight of the earth behind it. The triangular prisms of earth included between the edges of the steps form a plane of cleavage, against which the pressure of the back filling will act with practically the same effect which it would have upon the sloping surface of a smooth concrete wall of the same cross section.

As to the relative strength of concrete made with gravel or with crushed stone, laboratory tests undoubtedly show that the stone concrete is somewhat stronger. If tests were made of samples taken from actual construction work the difference would be reduced to a negligible quantity. But gravel has a considerable advantage in the matter of ease of handling wherever hand work is used; it is easier to shovel into barrows or carts and the concrete flows more readily through chutes; it can be placed more easily in the forms and packs better around the reinforcing bars.

In designing the retaining walls illustrated, no attempt was made to utilize the full compressive strength of the concrete; this, as Mr. Hoyt says, would have required a much greater amount of reinforcement than was used and would also have developed an amount of strength not required. Sections at the top of the footing, at the angle in the back of the wall, and at points both above and below this angle, were considered, the stresses computed by Prof. Howe's formulas and an amount of reinforcement provided sufficient to carry the total tensile strength at every point. The Johnson corrugated bars of ½ in. size were used, thus securing a better distribution of metal and a better design than could be had with larger bars. It is probable a thinner wall with more reinforcement and which would be cheaper, at least on paper, could have been designed. Such a wall, however, would have required buttresses and the necessarily complicated and expensive form-work. On account of the limited working space in the forms for high thin walls, the expense of placing reinforcement and concrete is greatly increased; much of the apparent advantage of the thin wall is lost as a result. In the work here considered, ease and rapidity of construction were of the utmost importance, and the design used was selected because it combined these features with a much lower cost than that of a plain wall.

The footings of these walls do extend outside of the railway company's right of way and into the adjoining street. The surface of the sidewalk intersects the face of the wall at the street line, which is also the line of the right of way.

Referring to Prof. Talbot's question concerning the stresses at the intersection of the bars at the angle in the back of the wall, each set of bars extends past the intersection a distance about 18 in. These projecting ends are deeply embedded in the wall, thus resisting any stresses set up by the angle which the two sets make with each other, and transmitting the total tensile stress from the upper to the lower set of bars.

In designing the concrete box culverts, to which Prof. Talbot also refers, they are considered as a combination of simple beams. In constructing these culverts the bottom is first built to the extreme width of the structure, with the vertical bars for the side walls projecting from it. The side walls are then built up to the bottom of the roof and last the roof is put on. Thus the floor and roof become simple beams supported by the side walls, which are themselves simple beams supported by the vertical bars projecting into the floor and roof, together with the bond in the joints. The longitudinal reinforcement is intended to tie the structure together and to resist transverse cracking from settlement under high fills.

Replying to Mr. Allen's request for a description of the C. B. & Q. Ry. track elevation subways, each subway is 66 ft. wide between abutments and has three rows of steel columns and cross girders, one at each curb line, and one in the center of the street. The columns rest on circular concrete foundations 3 ft. 8 in. in diameter, carried down to rock or hard pan at an average depth of about 40 ft. The columns and cross girders, together with the abutments, carry a solid deck of reinforced concrete slabs covering the entire space between right of way lines. The floor slabs, as already described, are built in units, about 7 ft. wide, which are placed side by side with the joints caulked to prevent leakage. Upon this floor of concrete slabs, ballasted tracks are placed. This type of construction is much cheaper than an all-steel structure and permits the tracks to be placed in any position desired, or to be shifted at any time. Trains passing over these bridges make no more noise than on an earth fill.

THE ROTARY CONVERTER SUB-STATION.

Presented before the Electrical Section, Dec. 21, 1906.

R. F. SCHUCHARDT, M. W. S. E.

In a system of electrical distribution using a pressure of 230 volts the economical limit of transmission is less than one mile where the load is dense and less than one and one-half miles with a scattered load, this limit being fixed by the amount and, therefore, the cost of copper necessary in the feeders to keep the loss from becoming excessive. When the territory served by the central station grows beyond this limit it becomes necessary either to increase the voltage or to add new stations.

The operation of many steam stations in various parts of the city is not conducive to high economy. Therefore an increase in voltage is resorted to in serving the larger territory. This is accomplished by a system of transmitting current at a high voltage from the main station to sub-stations located outside of the 230 volt limit, in which sub-stations the voltage is then stepped down to the distribution pressure. There is no definite relation necessary between the transmission and the distribution voltages, therefore any system of transmission can be adopted without regard to the distribution voltage.

In 1891 the celebrated line from Lauffen to Frankfort-on-the-Main in Germany, a distance of 110 miles, proved the feasibility and practicability of high voltage transmission by means of a three phase alternating current system. The dynamo in this instance was star connected and generated a pressure of about 50 volts star. This pressure was stepped up to 8000 volts delta and transmitted to the Frankfort Exposition where it was again stepped down to 50 volts.. The three phase system, thus proven, was rapidly adopted in all parts of the engineering world and many poly-phase transmission plants were installed. In America and in some European countries where this system is used to feed direct current districts the link between the alternating transmission current and the distributed current is the rotary converter.

Here in Chicago we have an excellent example of such a combined system where three phase currents at 9000 volts are generated in two steam stations and transmitted to rotary converter sub-stations scattered throughout the direct current districts and on the various railway systems of the city. How important a part of the entire system these sub-stations have become is well illustrated by their rapid growth, as shown in Fig. 1, which is a curve of the increase in converter capacity during the past ten years.

The initial three-phase transmission system in this city consisted of a 2250 volt, 25 cycle line operating from an inverted rotary and step up transformers at the Harrison Street Station and feeding two 100 k w. 115 volt rotary converters at the 27th Street substation. Such was the humble beginning of the very extensive system of high tension transmission lines and sub-stations, which at four times the initial pressure of 2250 volts, is now in operation in Chicago. Fig. 2 is a map showing the present lines, stations and sub-stations. The total length of these present transmission lines is approximately 240 miles.

I shall not attempt to discuss the design of sub-stations but rather to take them as we find them here in Chicago and describe briefly the essential parts and the manner of using these parts in order to get from them efficiently the desired results.

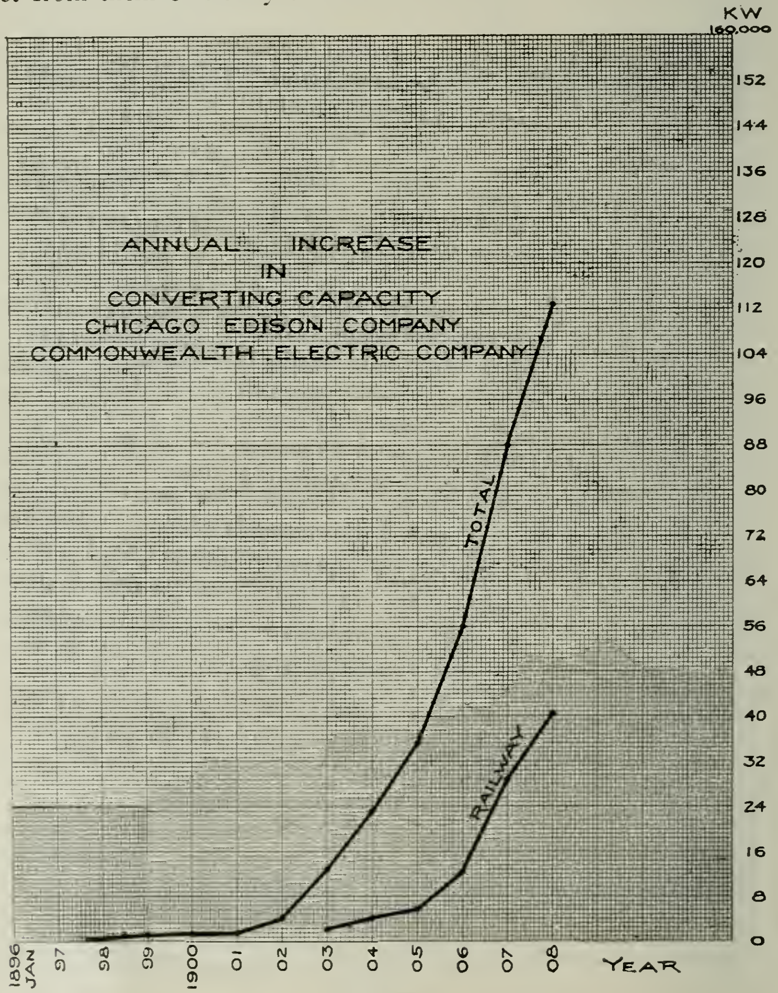
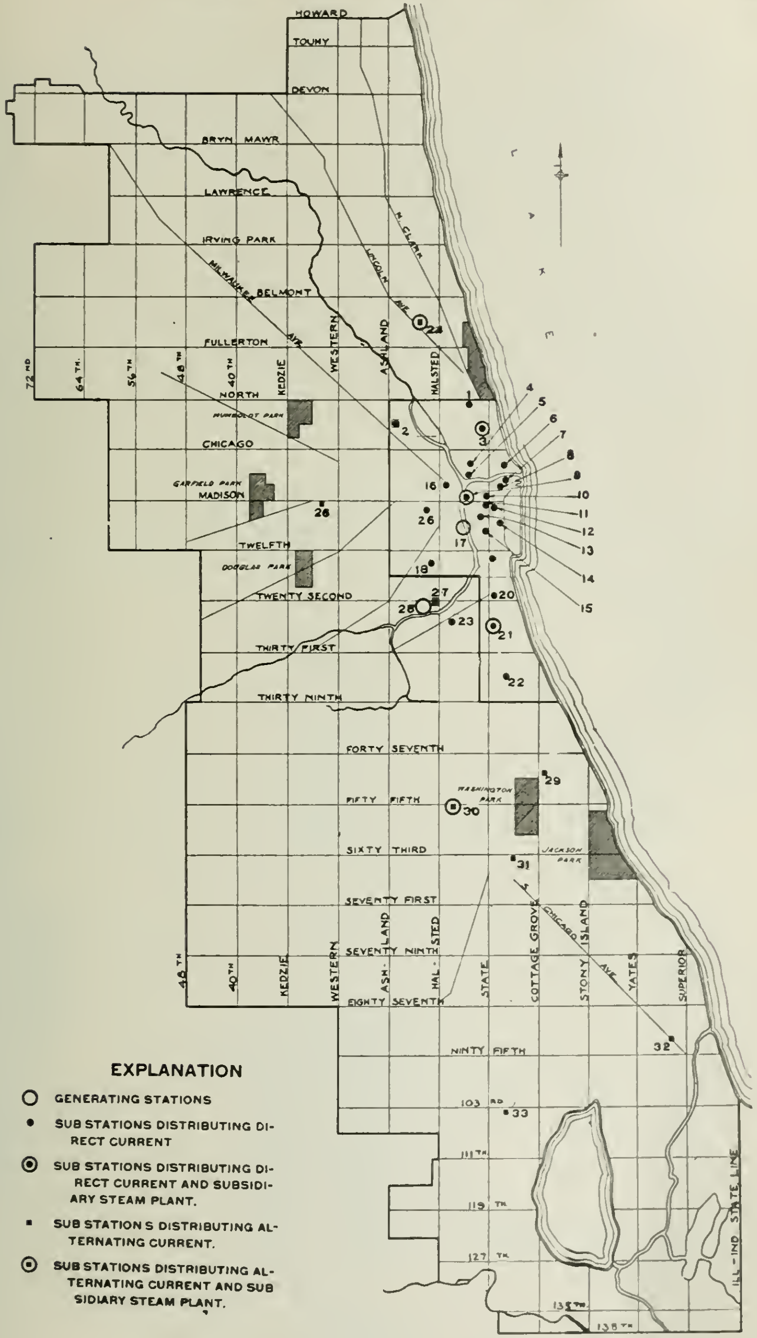


Fig. 1.


HOWARD
TOUHY
DEVON
BRYN MAWR
LAWRENCE
IRVING PARK
BELMONT
FULLERTON
NORTH
CHICAGO
MADISON
TWELFTH
TWENTY SECOND
THIRTY FIRST
THIRTY NINTH
FORTY SEVENTH
FIFTY FIFTH
SIXTY THIRD
SEVENTY FIRST
SEVENTY NINTH
EIGHTY SEVENTH
NINTY FIFTH
103 RD
111 TH
119 TH
127 TH
135 TH
138 TH
MILWAUKEE AV
LINCOLN AVE
N. CLARK
72 ND
64 TH
56 TH
48 TH
40 TH
KEDZIE
WESTERN
ASHLAND
HALSTED
STATE
COTTAGE GROVE
STONY ISLAND
CHICAGO AVE
YATES
SUPERIOR
ILL-IND STATE LINE
HUMBOLDT PARK
GARFIELD PARK
DOUGLAS PARK
WASHINGTON PARK
JACKSON PARK
1
2
3
4
5
6
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EXPLANATION
○ GENERATING STATIONS
● SUB STATIONS DISTRIBUTING DIRECT CURRENT
⊙ SUB STATIONS DISTRIBUTING DIRECT CURRENT AND SUBSIDIARY STEAM PLANT.
▪ SUB STATIONS DISTRIBUTING ALTERNATING CURRENT.
⊙ SUB STATIONS DISTRIBUTING ALTERNATING CURRENT AND SUBSIDIARY STEAM PLANT.

Fig. 2.

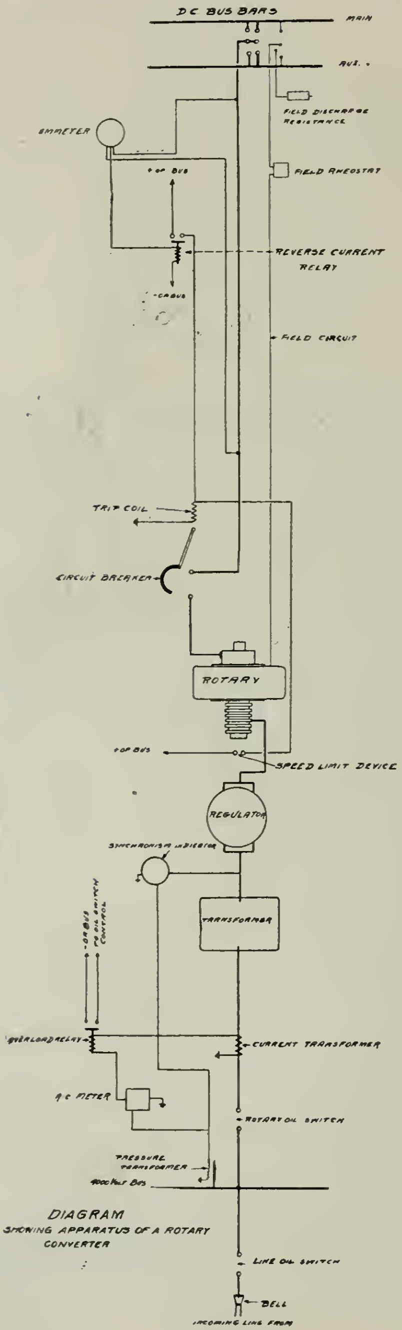


DIAGRAM
SHOWING APPARATUS OF A ROTARY CONVERTER

Fig. 3.

In Fig. 3 is a diagram showing the path of the current in the sub-station from the incoming a. c. lines to the outgoing d. c. feeders. The three-phase currents from the generating station enter over the high tension three-conductor lead covered cable, which ends at the line switch, where the conductors connect with the bus and then, through another switch with the step down transformer of a converter. From the transformer secondary the currents, now six phase and at reduced voltage, pass into the induction regulator which boosts or lowers the voltage as the load conditions require; thence they enter the rotary converter proper where the conversion to direct current takes place. From the d. c. brushes at the converter commutator the current is led to the direct current bus bars and then out into the system over the feeders. In addition to the parts just enumerated there are the pressure and current transformers, the meters, relays, etc., the purpose of all of which will appear later.

To take up the detailed description of the apparatus we begin where the current enters at the cable. In Fig. 4 is shown at (A) a sectional view of the cable bell where the lead sheath ends. The purpose of the bell is two-fold; first, to provide a receptacle for

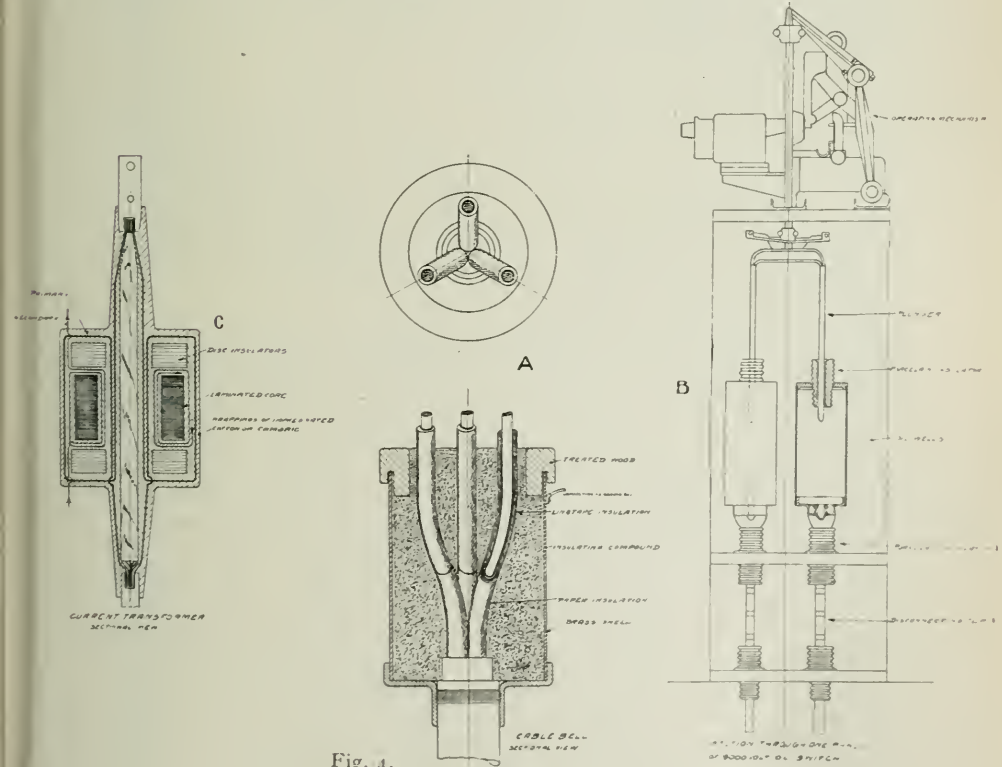


Fig. 4.

insulating compound at the point where the conductors are spread and part company, each going to its proper compartment in the switch; and second, to flare out the metal sheath at its terminus so no sharp ends are left near the conductors for the static charge to accumulate and discharge and thus ultimately break down the insulation at this point. On the upper part of the conductors themselves the paper insulation is replaced by many wrappings of linotape.

In (B) of Fig. 4 is seen one of the three compartments of the oil switch. The well to the right is shown in section. The incoming conductor is connected to the bottom of the switch at one side, the outgoing conductor to the bottom at the other side. When the switch is open the circuit is broken in the two oil wells in series. The removable blades at the base of the switch provide means for entirely disconnecting the oil wells from either side.

The current transformer is another piece of apparatus of which the outside is more familiar to us than the inside. Fig. 4 C is a sectional view of such a transformer.

Before going further in this description I shall spend a few minutes in attempting to explain vector diagrams, because the principle of operation of the apparatus can be much more easily understood by referring to such diagrams.

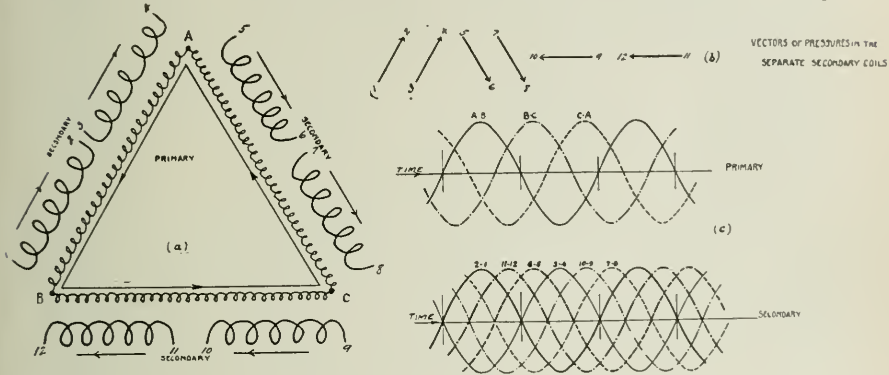
VECTOR DIAGRAMS.

The word *vector* is derived from the Latin *vectum,* to carry. Webster defines it as "A directed quantity, as a straight line, a force or a velocity. Vectors are said to be equal when their directions are the same and their magnitudes equal. (Note) In a triangle either side is the *vector sum* of the other two sides taken in proper order; the process of finding the vector sum of two or more vectors is *vector addition.*"

In alternating current discussion, we use vectors to denote the intensity or quantity of pressure or of current or of any other electrical dimension such as resistance, impedance, condensance, etc., and also the direction of these intensities or quantities with respect to some reference direction. The horizontal line is usually taken as the reference line, the direction toward the right being considered the starting point or zero time. As time progresses the vector swings around (the counter clockwise rotation being the one usually used) and when it has completed an entire revolution it has passed through one cycle or 360°. The instantaneous values of the intensities are the projections of the vectors on a vertical line. Thus at an angle of 90° the intensity is at a positive maximum and at 270° it is at a negative maximum, while at 0° and at 180° it is zero, the variation following the law of harmonic motion. By referring to a complete cycle of a sine wave (curve of harmonic motion) this is readily seen to be the case. The angle thus represents the time which has elapsed from the instant represented by the reference line. If a vector of pressure in a 25 cycle circuit is shown as having moved through an angle of 45° this represents an actual time interval of ⅛ of 1/25 or 1/200 of a second, each complete cycle consuming 1/25 second of time.

In a three phase system we have three separate pressures following each other by one-third of a cycle or 120°. That is, their phase difference is 120°.

Now let us see the application of this to our subject. In Fig. 5 (a) we see the coils of a three-phase transformer (or three single transformers on a three-phase system) and their vectors of pressure. The secondary pressure of a transformer is ap-



RELATION OF PRESSURES IN TRANSFORMER COILS
3-PHASE TO 6-PHASE TRANSFORMATION

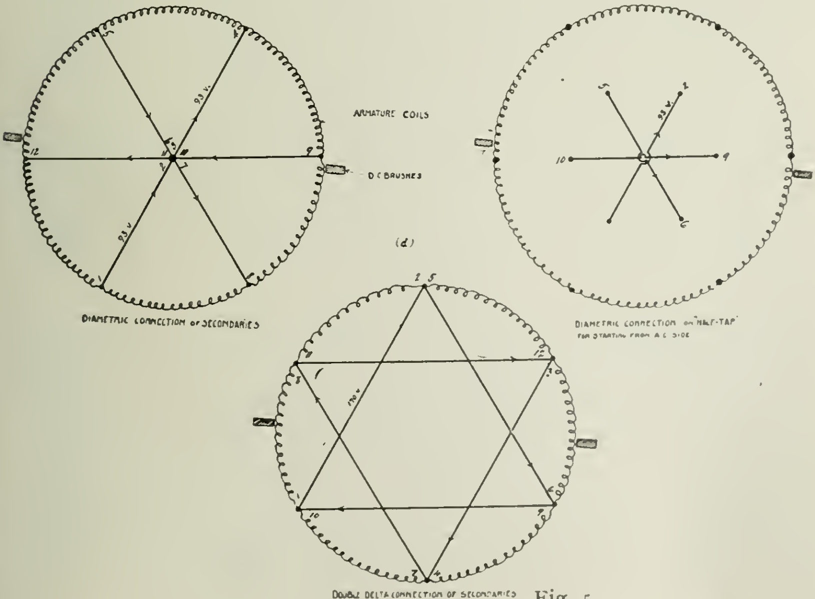

ARMATURE COILS
D C BRUSHES
(d)
93 V.
93 V.
12
9
10
9
93 V.
1 2
5
12
11
10
9
4 3
DIAMETRIC CONNECTION OF SECONDARIES
DIAMETRIC CONNECTION ON "HALF-TAP" FOR STARTING FROM A C SIDE
DOUBLE DELTA CONNECTION OF SECONDARIES

Fig. 5.

proximately 180° in phase relation to the primary pressure. The delta of primary pressures represents the relative phase of these pressures as they come from the generator. In the secondaries we have six coils and, therefore, six pressures, the vectors of which are shown in Fig. 5 (b). The waves of these pressures are given in Fig. 5 (c). These pressures can be combined in any manner that we choose. In the earlier units, where three single-phase transformers were installed the so-called "double delta" combination, shown in Fig. 5 (d) was used, each secondary coil being wound for 170 volts (for a 250 volt d. c. converter). In the three-phase transformer the "diametric" connection is usual. In this case the middle points of each secondary pair are brought together and connected through a switch to the neutral of the three wire system. Such a unit is thus also a balancer. In the diametric connection each coil is wound for 93 volts, the diametric coil being two in series or 186 volts. In both of the above the secondaries form a six phase connection.

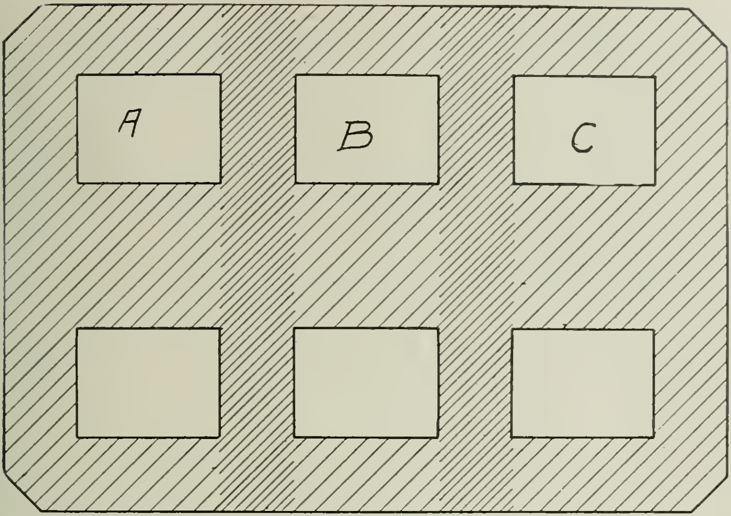
TRANSFORMER.

In the three-phase transformer, of which a section of the core is shown in Fig. 6 (a), the connections of the middle coil are reversed with respect to the other two. The reason for this becomes apparent when we consider the vectors of current and magneto motive force (m. m. f.). The magneto motive force (that is the magnetic pressure) is 90° in phase behind the current which produces it. In 6 (b) are shown the vectors of the currents and m. m. f. with B not reversed. Referring to 6 (a) the double shaded portion of the core between coils A and B has a magnetization due to coils A and B, *i. e.,* its magnetic motive force is the resultant of the m. m. fs. of A and B. In 5 (c) the m. m. fs. of A and B are shown combined, the resultant being 1.732 times as great as either A or B. The same holds for B and C. By reversing B coil, and thus its m. m. f., the resultant magnetic density will be the same in all branches of the core as shown in 6 (d).

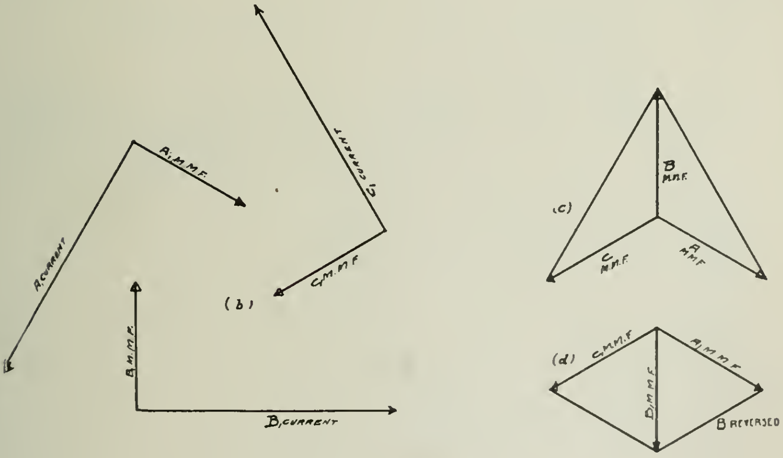
It may be of interest to know that in our standard 1100 kw. three-phase transformers there are 386 turns in each phase of the primary and 8 turns in each phase of the secondary.

REGULATOR.

We next come to the regulator. This is in effect a six-phase transformer in which the phase of the secondary pressure can be varied through 180°, that is, from the position in phase with the pressure from the transformer secondaries, which is maximum boost, to that directly opposite, which is maximum choke. To illustrate the action of the regulator let us take a core and wind on it three coils placed 120° from each other. We will connect these three coils to the wires of a three-phase system so the three pressures or currents or magnetizations can be represented by three



SECTION OF CORE OF G.E. THREE-PHASE TRANSFORMER
(a)



VECTORS OF CURRENTS AND MAGNETO-MOTIVE-FORCES IN THREE PHASE TRANSFORMER, SHOWING REASON FOR REVERSAL OF MIDDLE COIL

Fig. 6

waves as in Fig. 5 (c). By following these waves we note that when one is at a maximum in the positive direction the other two are both negative, one is increasing and the other decreasing. One-third cycle later the second wave reaches its positive maximum and then the third and so on. As a result, the magnetizations set up by these separate currents, follow each other around the core so we have a constant rotating magnetic field and not an alternating field as in a single phase transformer. The induced secondary pressures in the regulator are thus practically constant and are not affected in amount by the movement of the primary. Their phase, however, is affected by the position of the primary and this is what determines the amount of the boost or the choke. This is illustrated in Fig. 7 (a) where O S represents the secondary pressure of the transformer, S R the secondary pressure of the regulator and O R the resultant pressure impressed on the converter. Fig. 7 (b) shows the vectors of these pressures for all six phases, the regulator being shown as choking. The range of the regulation in a. c. six-phase pressure is from 9 to 12 volts. The movement of the primary is effected by means of a small motor which is geared to a quadrant fastened to the shaft of the primary. It is by thus varying the a. c. voltage at the converter itself that the d. c. pressure and the division of load is regulated (Fig. 15.)

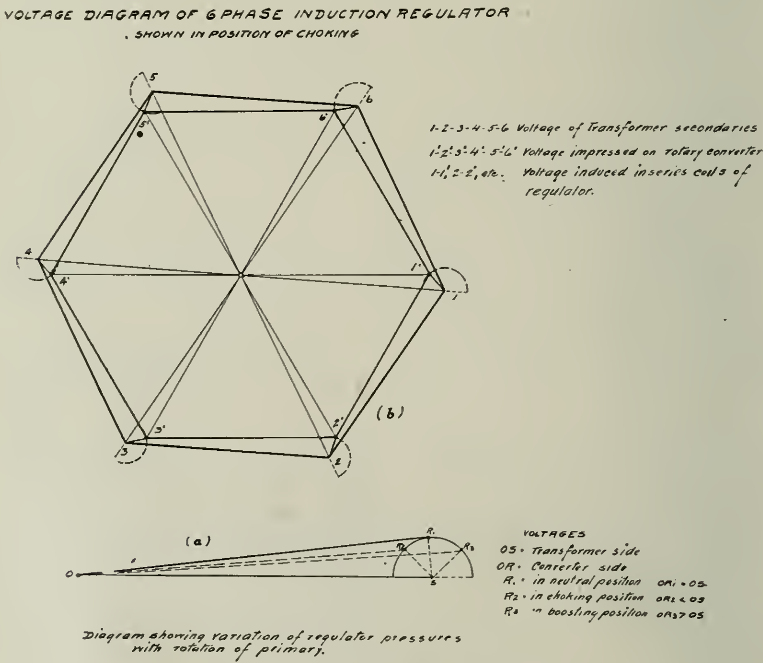

VOLTAGE DIAGRAM OF 6 PHASE INDUCTION REGULATOR
SHOWN IN POSITION OF CHOKING
5
6
5'
6'
4
4'
1'
1
3
3'
2'
2
(b)
1-2-3-4-5-6 Voltage of Transformer secondaries
1'-2'-3'-4'-5'-6' Voltage impressed on rotary converter
1-1', 2-2', etc. Voltage induced in series coils of regulator.
(a)
O
R1
R2
R3
S
VOLTAGES
OS = Transformer side
OR = Converter side
R1 = in neutral position OR1 = OS
R2 = in choking position OR2 < OS
R3 = in boosting position OR3 > OS
Diagram showing variation of regulator pressures with rotation of primary.

Fig. 7.

ROTARY CONVERTER.

Now we have come to the rotary converter itself. This is merely a d. c. generator with taps brought out from equidistant points on the armature winding and connected to collector rings to make it also an alternator. It can be used as a. c. synchronous motor, as d. c. shunt motor or as a d. c. or an a. c. generator. When used as a combined a. c. motor and d. c. generator, that is, as a *rotary converter,* it is capable of a considerably greater output than when operated as any of the above alone. This is due to the fact that much of the current in going from the a. c. brushes to the d. c. brushes does not pass through all of the armature conductors as the path is more direct during the greater part of each revolution.

The rating of the converter based on heating is given by Steinmetz as follows:

D. C. generator	1.00
Three-phase converter	1.31
Six-phase converter	1.94

That is, when used as a six-phase converter the capacity of the machine is nearly double that when used as a d. c. generator.

The theoretical ratios of a. c. to d. c. pressures in a converter are as follows:

Diametric to d. c.	70.7%
Three-phase to d. c.	61.2%
Six-phase to d. c.	35.4%

These ratios are based on sine waves which are rarely obtained in practice. The actual ratio is somewhat larger, due to wave shape, to armature losses, etc., (Fig. 17.)

A field "break-up" switch is provided whereby the field circuit can be opened at several points in series, leaving comparatively few poles connected to each other. The purpose of this is to prevent the induced voltages in the field circuit from becoming too high (many spools added in series) when the unit is started from the a. c. side. The switch is double throw to provide means for rapidly correcting the polarity should it come up reversed when so started. Frequently damping coils or grids are placed on the field poles to lessen the tendency toward hunting. These coils also add to the stability of the converter during disturbances on the system. An end play device is provided to move the armature latterly at regular intervals in order to equalize the wear of the brushes on the commutator and the collector rings, particularly the latter as the a. c brushes are of copper.

METERS, INDICATORS, ETC.

Referring to Fig. 8, we see the connections and interconnections of the parts just described and of the meters, relays, etc. The a. c. meters, which measure the 9000 volt energy, are not directly con-

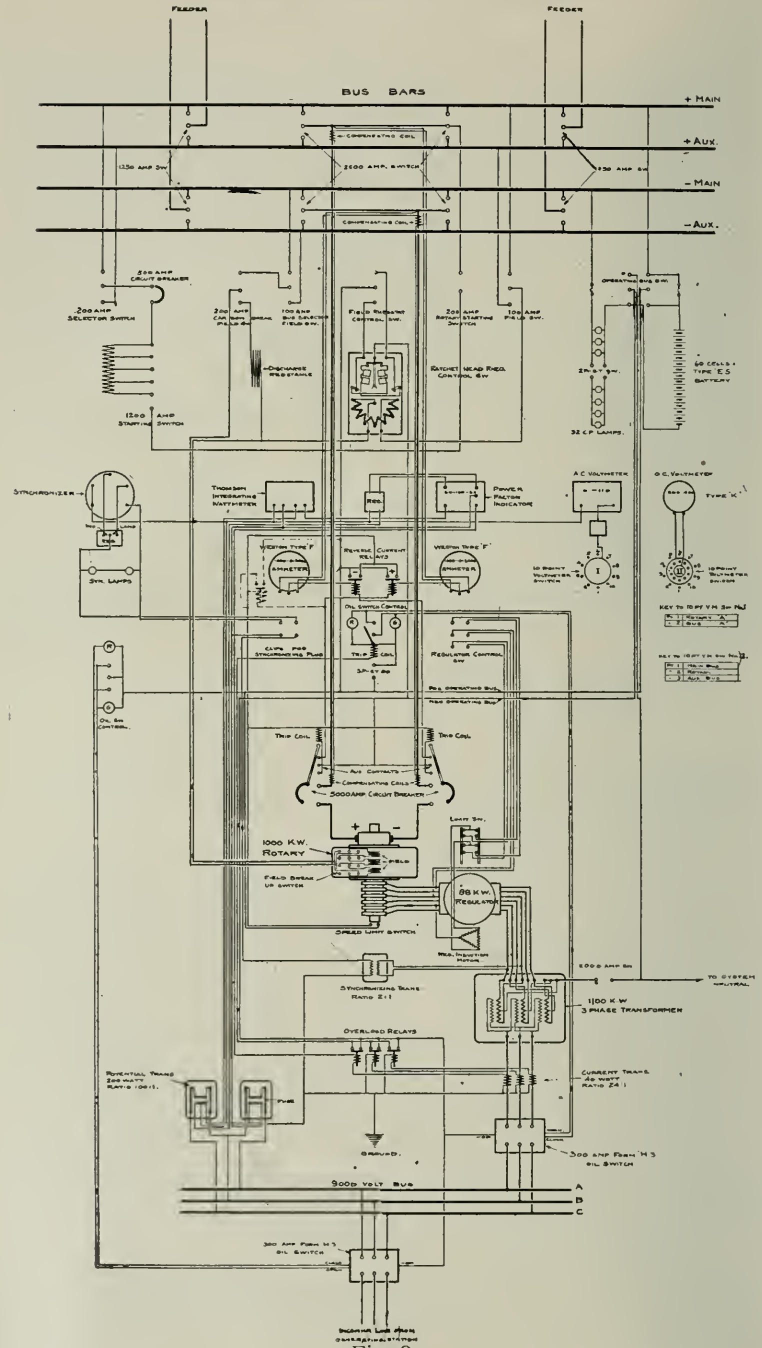

Feeder
Feeder
Bus Bars
+ Main
+ Aux.
– Main
– Aux.
Compensating Coil
1250 Amp Sw.
2500 Amp. Switch
1250 Amp Sw.
Compensating Coil
500 Amp Circuit Breaker
200 Amp Selector Switch
200 Amp Car Bon Break Field Sw.
100 Amp Bus Selector Field Sw.
Field Rheostat Control Sw.
200 Amp Rotary Starting Switch
100 Amp Field Sw.
Operating Bus Sw.
Discharge Resistance
Ratchet Head Rheo. Control Sw.
2P-DT Sw.
60 Cells Type E S Battery
1200 Amp Starting Switch
32 C P Lamps.
Synchronizer
Thomson Integrating Wattmeter
Reg.
Power Factor Indicator
A C Voltmeter
D C Voltmeter
Type K
Ind.
Lamp
Syn. Lamps
Weston Type F
Ammeter
Reverse Current Relays
Weston Type F
Ammeter
10 Point Voltmeter Switch
I
II
10 Point Voltmeter Switch
Key to 10 Pt V M Sw No. I
Pt 1 Rotary A
" 2 Bus A
Key to 10 Pt V M Sw No. II
Pt 1 Main Bus
" 2 Rotary
" 3 Aux. Bus
Oil Switch Control
R
G
Clips for Synchronizing Plug
Trip Coil
S.P.-S.T. Sw
Regulator Control Sw
Pos. Operating Bus
Neg. Operating Bus
R
G
Oil Sw. Control
Trip Coil
Trip Coil
Aux. Contacts
Compensating Coils
5000 Amp Circuit Breaker
+
–
Limit Sw.
1000 K.W. Rotary
Field
Field Break Up Switch
88 K.W. Regulator
Speed Limit Switch
Reg. Induction Motor
Synchronizing Trans Ratio 2:1
2000 Amp Sw.
To System Neutral
1100 K.W 3 Phase Transformer
Overload Relays
Current Trans. 40 Watt Ratio 24:1
Potential Trans 200 Watt Ratio 100:1.
Fuse
Ground.
300 Amp Form H 3 Oil Switch
9000 Volt Bus
A
B
C
300 Amp Form H 3 Oil Switch
Incoming Line from Generating Station

Fig. 8.

nected to the high tension conductors. Such connection would require very expensive and difficult construction. Therefore a potential transformer is used to step down the pressure and a current transformer for obtaining the meter current entirely insulated from the high tension conductor. In principle these transformers are the same, the difference between the two being one of design to conform to the different conditions. The pressure transformer is connected in shunt across the line while the current transformer is connected in series, as is shown in the diagram. The watt-hour meter is connected so as to receive current from one of the phases and pressure between that same phase and a point midway between the other two phases. With a balanced load such as a rotary converter the meter will with this connection register one-half the total three-phase energy. The unit is also provided with a power factor indicator, so the operator can know when his apparatus is operating at the highest efficiency with regard to current input. This indicator is very interesting and it will be worth while to study the principle on which it operates.

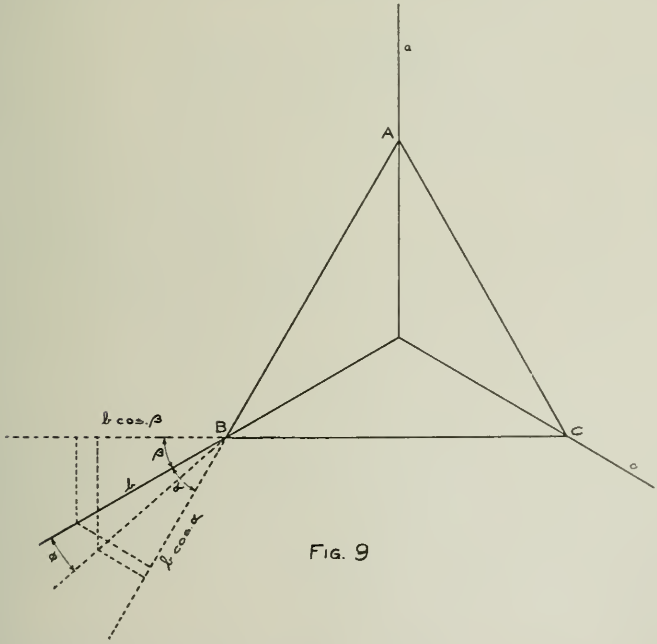


Fig. 9

In a balanced three-phase system we have pressures as represented by the delta A B C, Fig. 9, the phase of the corresponding currents at unity power factor being shown by the lines a b c. A one-phase wattmeter connected with its current coil in b and taking pressure from A B would have a torque represented by A B.b cos. α

If taking pressure from B C instead of A B the torque would be B C.b cos β. With a lagging current, the angle α will decrease and angle β will increase by an amount represented by ; cos α will thus increase while cos β decreases. By taking a wattmeter provided with two pressure coils connected respectively to A B and B C while the current coil is on b phase, and by arranging these two pressure coils to give torque to the moving element each in an opposite direction we have a power factor indicator. At unity power factor A B.b cos ϕ equals B C.b cos β so each pressure coil will exert an equal torque and the needle will stand in the center of the scale. As the phase of the current is changed, either leading or lagging, one of the torques decreases while the other increases and the needle is thus moved to one side or other by an amount depending on the angle of lead or lag.

The synchronism indicator, frequently termed synchronizer, is another piece of apparatus which is far more simple than is generally thought. Let us take two coils having the same axis, one of these coils fixed and the other movable about its axis. If now we connect these coils in series so the phase of the current in each will be the same, the movable coil will place itself in the plane of the fixed coil. If the current is reversed in one of the coils the movable coil will swing around and place itself at 180° from the first position. Instead of reversing the current, that is, changing it in phase by 180° let us change the phase of one of the currents by 90°. The coils will then set themselves at right angles to each other, midway between the first and second position. In this position there is of course no torque between the two coils. Now add a second coil fixed to the movable coil and at right angles to it. Connect these two coils in parallel on the same circuit but insert in series with one of then a non-inductive resistance and in series with the other a high reactance. The currents in these two coils will then have a phase difference of approximately 90°. With these two coils swinging within the fixed coil there will thus be no position of zero torque for the system, as one coil will have maximum torque when the torque due to the other is at zero. The angular position of the movable coils, or armature of the synchronism indicator, will thus always correspond to the angular displacement of the pressures of two systems one of which is connected to the fixed or field coil and the other to the armature coils. A pointer is fastened to the armature and indicates the phase relation between pressures that are being compared.

The d. c. ammeters, as is shown in Fig. 8 and Fig. 10, do not have the entire current pass through them. They are really millivoltmeters based on Ohm's law. They measure the milli-volts drop across a certain section of the cable through which the current passes, this drop varying directly with the current. To compensate for changing resistance of the copper cable at different temperatuers a copper compensating coil is inserted in series with the meter

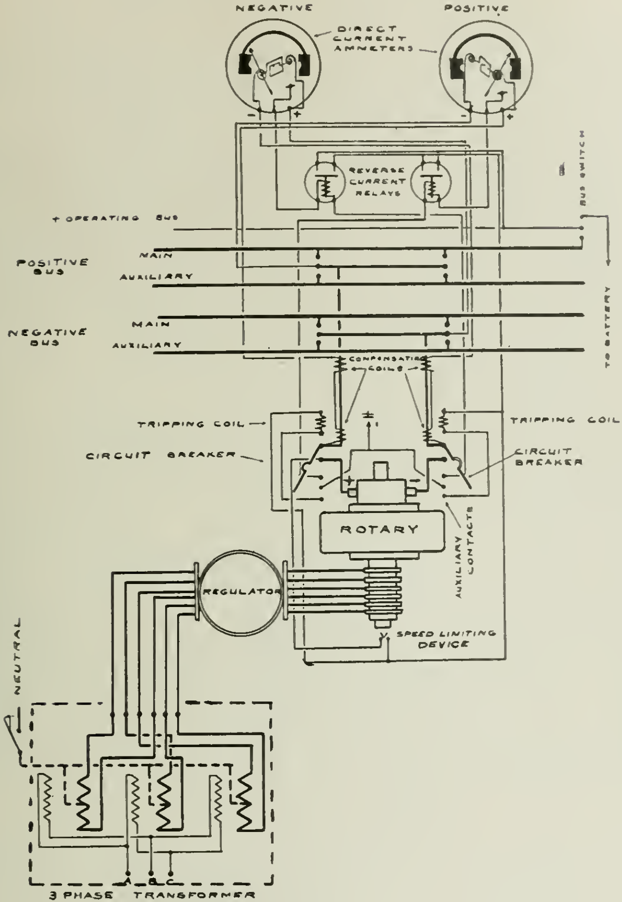


Fig. 10.

circuit. This coil is closely wrapped around the cable so that both will be at the same temperature. An increase in cable resistance due to heat will thus cause a corresponding increase in the compensating coil resistance. By making the resistance of this coil large, compared with the meter resistance, the heating error can be made negligibly small. Often the compensating coil is made in sections placed at different parts along the cable so as to get the proper correction for the mean temperature of the cable.

PROTECTIVE DEVICES.

The automatic protective devices consist of an overload circuit breaker on the a. c. side and of reverse current relays and speed limit device operating on d. c. circuit breakers. There is also an overload circuit breaker in the d. c. starting circuit. The a. c. overload relay acts directly on the high tension oil switch and is provided with an inverse time element of the bellows type. The connections of the d. c. protective devices are shown in Fig. 10. The speed limit device is an ordinary centrifugal switch which closes the tripping circuit at a predetermined excessive speed. The reverse current relay is actuated by current over the ammeter leads, its circuit being closed when the ammeter needle is deflected to the end of the scale in the reverse direction as shown. The connections are such that when the contact is made, due to reverse current, the current flowing through the meter coil will be in a direction to increase the pressure on the contact. The reverse scale is generally from 25 to 50% of the rated load of the unit.

As the capacity of the electrical apparatus is limited by its heating, any arrangement which will keep the apparatus cool will add to its capacity, or, for the same output the apparatus can be designed with less generous proportions and, therefore, be built considerably cheaper if designed to operate in connection with a cooling device. For this purpose a motor driven blower is installed to furnish a supply of cool air which is blown through the apparatus and thus carries off much of the heat. The energy required for this purpose averages about 3 H. P. per sub-station unit, the air pressure approximating one ounce. The difference in blower capacity required for a 500 kw. unit and a 1000 kw. unit is small. The energy is thus approximately 0.1 and 0.2 per cent respectively of the rated capacity of the two units.

It is thought that a table of some of the dimensions may prove of interest and it is given in Fig. 11.

RAILWAY SUB-STATION.

We next come to the railway sub-stations. Fig. 12 is a diagram of the connections of a G. E. railway converter. The secondary coils of the step-down transformers of this unit have taps for one-third and two-thirds of full pressure, these being for the purpose of starting the converter from the a. c. side, as shown by the two three-pole double-throw switches. The protective devices shown consist of an a. c. overload coil and an overload and speed limit circuit breaker on the d. c. side. It is good practice to install also a reverse current relay connected to the d. c. circuit breaker when the converter is operating in parallel with a storage battery. The diagram shows no voltage regulator such as is installed with the converters first described. Instead, reactive coils are provided, the purpose of which will be explained later.

STARTING.

In Fig. 13 connections are shown for starting rotary converters, the upper diagram for d. c. starting and the lower for a. c. starting. The d. c. arrangement varies somewhat in the different sub-stations.

APPROXIMATE ELECTRICAL DIMENSIONS ETC

FIG. 11.

TRANSFORMER.

K W CAPACITY	PRI. VOLTS	FULL LOAD PRI. AMP.	SEC. VOLTS.	FULL LOAD SEC. AMP	RES. PER PHASE		WEIGHT	REMARKS
					PRI COIL	SEC. COIL		
185	9000	20.6	170	1090	2.1	.00144	6200 LBS.	SINGLE PHASE
550	9000	21 PER COIL 35.3 PER PHASE	186	985	2.5	.0011	13500 LBS	3 PHASE
1100	9000	42 PER COIL 70 PER PHASE	186	2000	1.1	.0008	20100 LBS	3 PHASE
2200	9000	84 PER COIL 141.2 PER PHASE	198	3100	.4	.0003	39600 LBS.	3 PHASE

INSULATION RES. OF PRIMARY 30 TO 120 MEGOHMS AVERAGE ABOUT 80 MEGOHMS.

REGULATOR.

FOR K.W UNIT	K W CAPACITY	PRI. VOLTS	SEC. AMP.	PRI. RES DIA. COIL	SEC. RES PER PHASE	WEIGHT
500	65	170	925	.026	.000408	5600
500	44	186	1000	.027	.00019	6000
1000	88	186	2000	.015	.00015	9000
1000-300 VOLT	140	244	1875	—	—	10500
2000	280	200	3700	.003	.00010	16000

ROTARY CONVERTER.

CAPACITY	FULL LOAD AMP	RES. OF ARM *	RES OF FLD	RES OF FLD RHEO	RES OF FLD DISCH	RES OF STARTING BOX	WEIGHT
500	2000 (250V)	.005	18	47	40	1.00 OHMS.	18 TO 20 TONS
1000	4000 (250V)	—	10	18	30	.27 "	34 TONS
2000	7410 (270V)	—	2.7	8.2	1.3	.16 "	81 TONS

* DOES NOT INCLUDE RES. OF BRUSHES AND BRUSH CONTACT

WIRING DIAGRAM OF
G. E. RAILWAY ROTARY CONVERTER

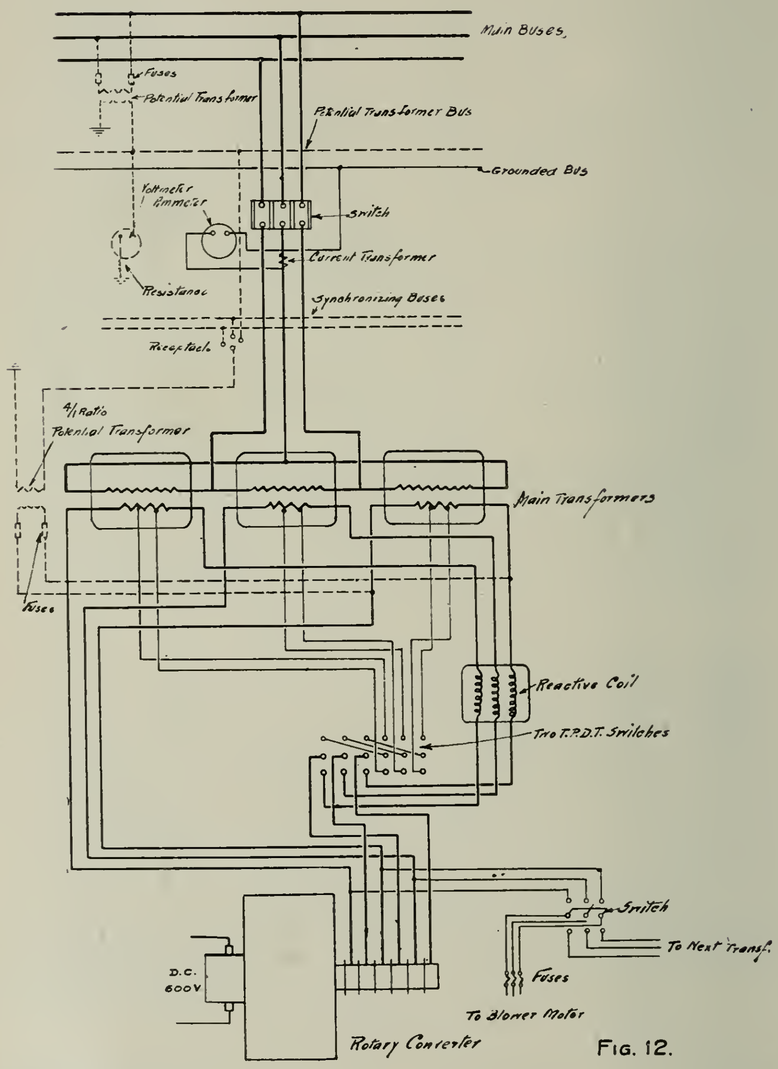


FIG. 12.

New installations will be connected with fields self-excited as shown in Fig. 14. Starting from the d. c. side is accomplished in the same manner as for any shunt motor, by means of the starting box shown in the diagram. Connection to the starting bus is made through a removable blade, this blade being common for all units and only one provided for each sub-station. This prevents the liability of short circuits being accidentally made through the starting bus. Only one unit can thus be started from the d. c. side at a time. The regulator and transformer secondaries are of course connected during starting and this results in diverting some of the

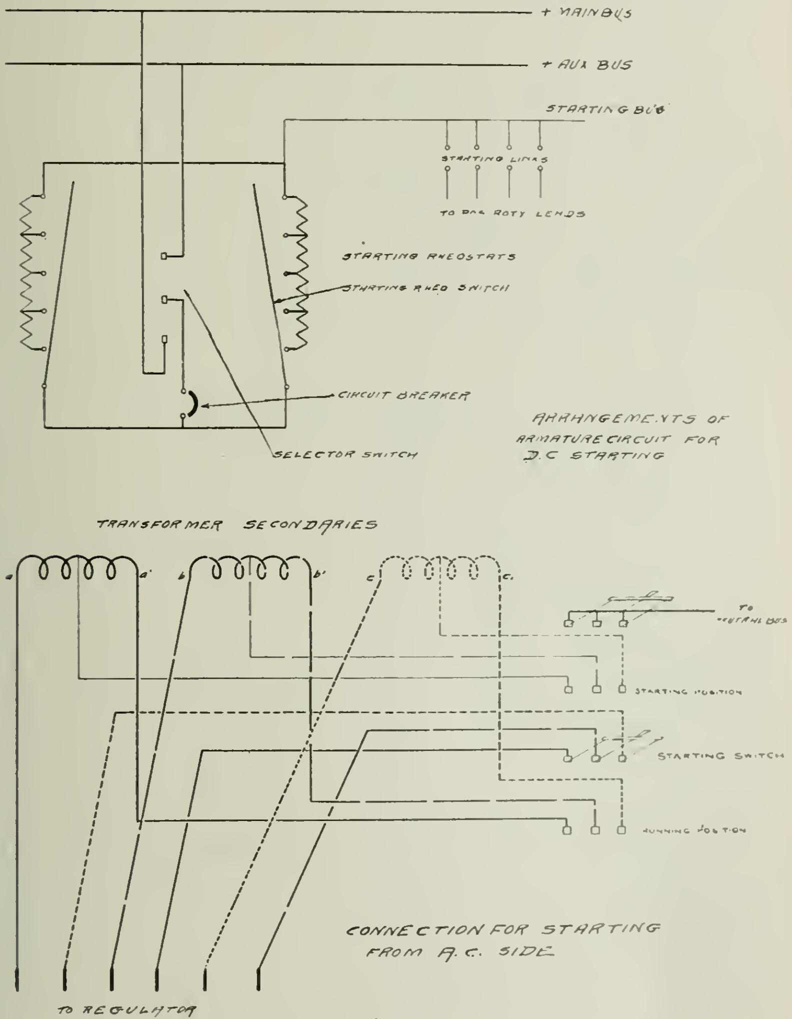


Fig. 13.

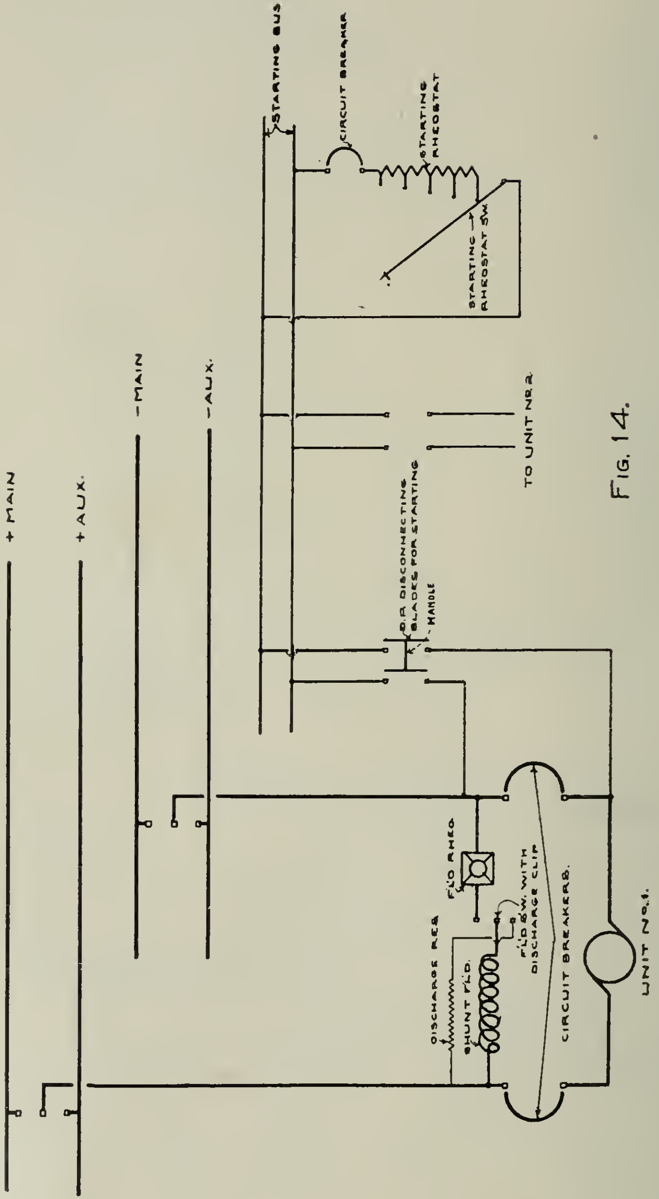

STARTING BUS
CIRCUIT BREAKER
STARTING RHEOSTAT
STARTING RHEOSTAT SW.
+ MAIN
+ AUX.
− MAIN
− AUX.
TO UNIT No.2
D.P. DISCONNECTING BLADES FOR STARTING
HANDLE
FLD RHEO.
DISCHARGE RES.
SHUNT FLD.
FLD SW. WITH DISCHARGE CLIP
CIRCUIT BREAKERS
UNIT No.1

FIG. 14.

starting current from many of the armature turns. The distribution of the current in the armature is thus not balanced and frequently it happens that the magnetic action between a strong field and the magnetically unbalanced armature holds the armature stationary. The field must then be weakened before the armature will rotate. The a. c. starting is done by means of a lower starting pressure, this being obtained by a half voltage tap as shown. The unit acts as a hysteresis motor when started from the a. c. side. The purpose of the field break-up switch in connection with a. c. starting has been mentioned before. The neutral connection to the middle points of the transformer secondaries can be seen in this diagram (Fig. 13).

The current required to start a 500 kw. unit from the d. c. side is about 650 amperes at 240 volts and about 850 amperes for the 1000 kw. unit. When started from the a. c. side the 500 kw. unit takes from 35 to 70 amperes, depending on the position of the regulator, while the 1000 kw. unit takes from 65 to 85 amperes. The smaller unit will come to synchronous speed in 8 to 12 seconds while the larger one requires 12 to 18 seconds. The time necessary for putting a unit on the system from rest, varies from one to four minutes, depending on the travel of the regulator quadrant which is required. The 500 kw. unit can be started from the d. c. side with 30 volts pressure while the 1000 kw. unit will start with 20 volts applied.

In starting a General Electric railway converter it is usual to start first from the d. c. side. When nearly up to speed the d. c. switches are opened and the a. c. oil switch is closed, the rotary connections being on the one-third tap. The field switch is then closed and polarity noted. If this is correct the a. c. starting connections are thrown over to the two-third tap and a few seconds later to the "full" tap. If the polarity comes up reversed it is corrected while on the one-third tap. This is done as follows: The field break-up switch is first reversed. The armature will then slowly slip back from synchronous speed, the d. c. voltmeter showing the progress. When the meter needle has passed zero it will come up in the proper direction. The field break-up switch is then thrown back into its normal position and the polarity will remain correct. If the connections permit closing the field on the d. c. bus the polarity can be corrected immediately by switching the field on the bus. This operation will cause a slight jolt on the system. The Westinghouse rotaries are started differently. They are provided with an induction motor on an extension of the shaft. This motor has less poles than the converter and is thus capable of a higher speed. By means of an inductance connected as load between two of the three-phase rotary leads (the field being closed) the speed can be lowered. By opening and closing this load circuit the converter can be brought to synchronous speed and in phase with the line.

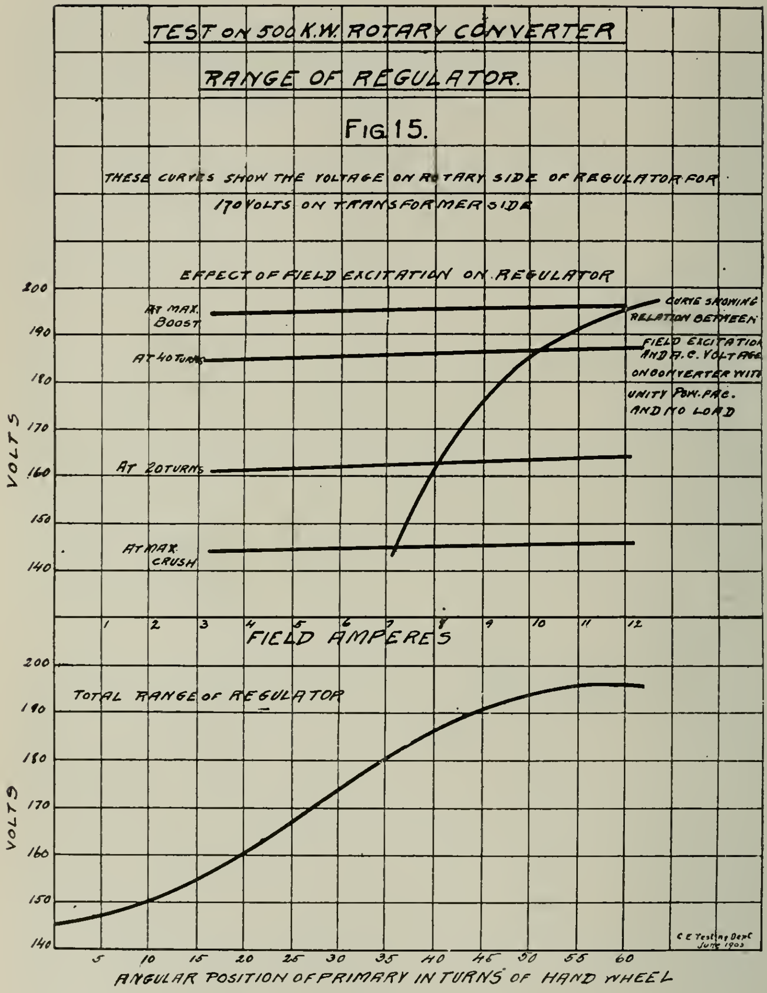


Fig. 15.

CONTROL OF LOAD.

The control of the load and voltage of the Edison system converters is accomplished by means of the induction regulator as already described. In Fig. 15 are shown curves of the regulator range and the effect on the range of varying field excitation. The upper curves show that the field strength has a very limited effect on the regulation. The influence of leading and lagging current on the conversion ratio is shown in Fig. 17. As already noted, the railway converters have no induction regulator. In them the regulation is effected by a comparatively high reactance in the a. c. circuit together with a compound winding on the field coils. The Westinghouse transformers are designed with a high reactive constant while the General Electric units are provided with a separate three-phase reactance coil. Reference to Fig. 18 will help explain this automatic regulation. With the current in the regulator (I.) at unity power factor, the reactive e. m. f. (E_1) in the coils is at right angles to the impressed pressure, for the e. m. f. of self-induction lags 90° behind the current. The resultant pressure ($O E_1$) is thus slightly greater than the impressed pressure. Due to the compound winding on the field, an increased load will cause the current to become leading (I_3) thus swinging the reactive e. m. f. in a direction so the resultant with the impressed e. m. f. will increase the converter pressure ($O E_3$). A lagging current, due to underexcited field, will similarly decrease the converter e. m. f. ($O E_2$).

Curves of efficiency and analysis of losses are given in Fig. 19.

CURVE SHOWING VARIATION
OF FIELD CURRENT WITH LOAD AT UNITY POWER FACTOR
FOR 500 K.W. AND 1000 K.W ROTARY CONVERTERS

FIG. 16.

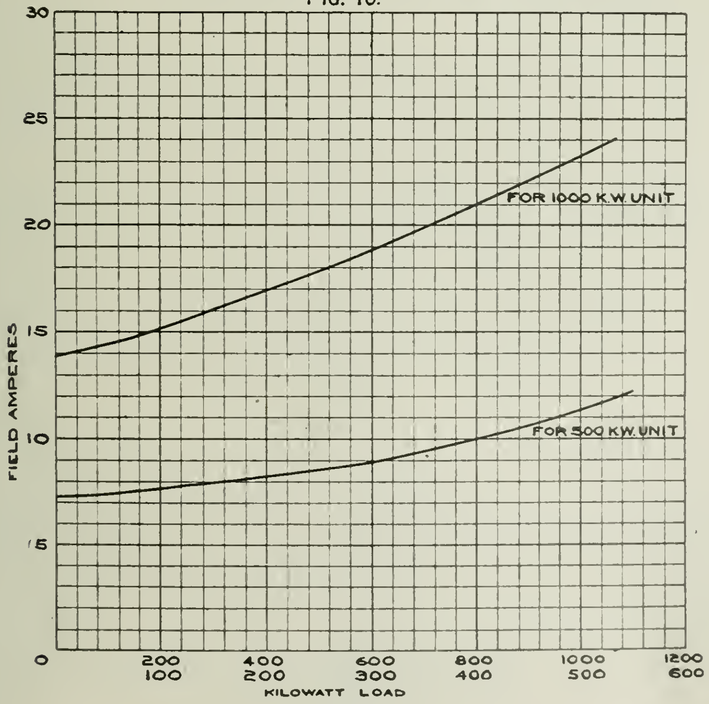


Fig. 16.

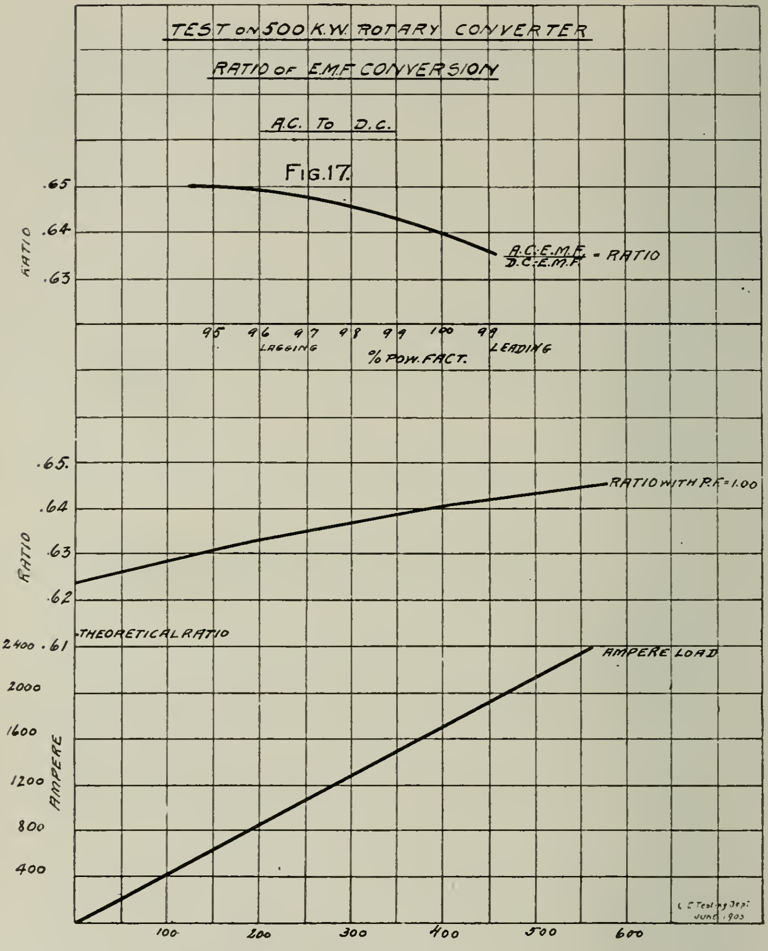


Fig. 17.

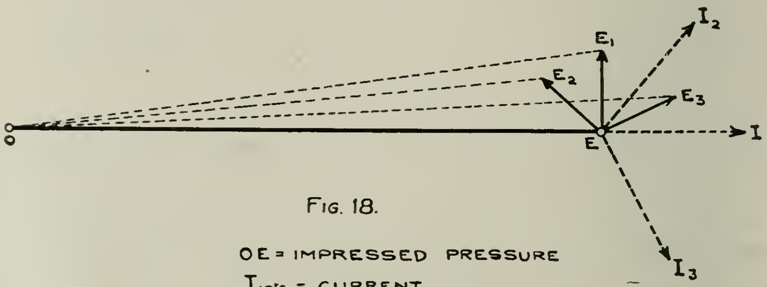


FIG. 18.

OE = IMPRESSED PRESSURE

I₁etc = CURRENT

E₁etc. = REACTIVE E.M.F.

They show a maximum efficiency for this 500 kw. unit of 89.8% at about three-quarters load. The high loss curve for the brushes, which includes the contact, shows the importance of using good brushes. The limit of capacity when operating on one side of the three wire system, *i. e.*, as a simple balancer, is set by sparking at the brushes at about rated full load current.

A few illustrations are added to show typical installations of the kind described. Fig. 20 is of the front of a switchboard of fairly modern construction. The clips for the starting blade and the blade itself are plainly shown. Two switches are connected in

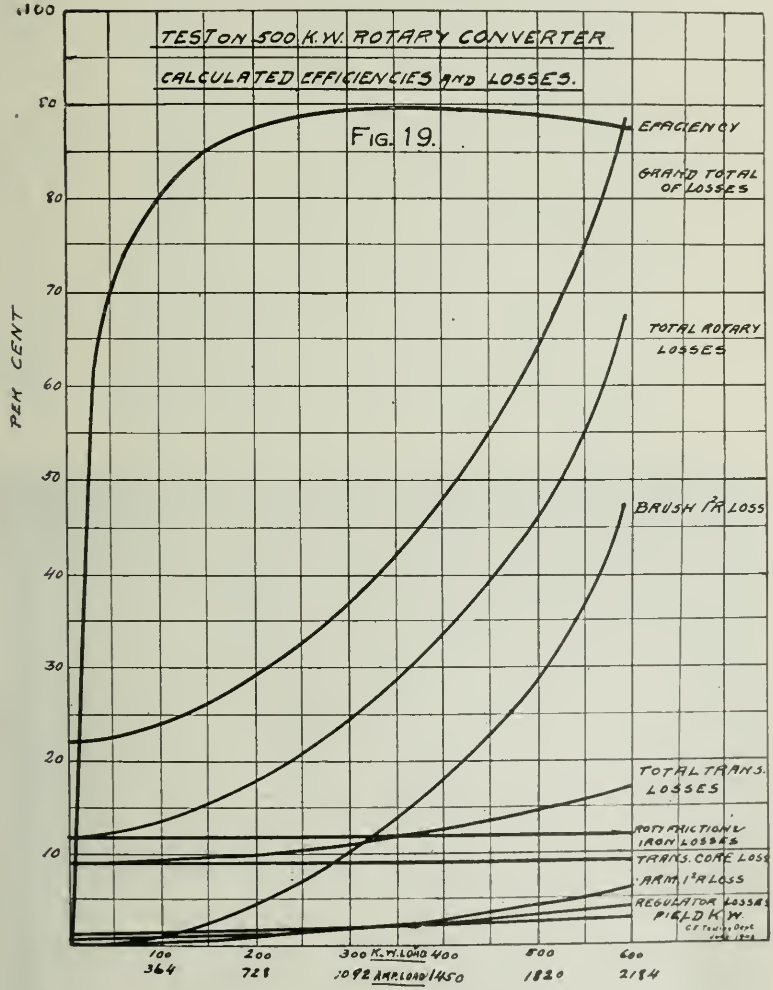


Fig. 19.

parallel on each polarity, each being double throw so they can be connected to the main or to the auxiliary bus.

The most recent construction of d. c. bus bars is illustrated in Fig. 21, the bars being laid horizontally. The increased space and accessibility that this gives to the connections can be appreciated by comparing with the right hand end of Fig. 22 where the older type of construction with vertical bars is shown.

In Fig. 23 is shown an installation in a basement with comparatively low ceiling. These are all 500 kw. converters. It may be of interest to note that vertical rotary converters are being developed which will permit the installation of 1000 kw. units with this same limited head room. Fig. 24 shows an installation of 1000 kw. units in a downtown basement, and in Fig. 25 are shown similar units in a sub-station built for the purpose.

In the middle of Fig. 26 is a 2000 kw. unit. The picture was taken before the operator's platform was erected on the converter.

A 1200 kw. G. E. railway converter is the subject of Fig. 27, while Fig. 28 shows a Westinghouse railway converter installation. In these latter the induction motor for starting can be seen.

There are a number of other points which I had hoped to touch on, such as the storage battery as an adjunct to the rotary converter sub-station, a comparison of our installations with those in other countries and other cities, the question of station economy, of the rotary efficiency versus brush economy, the periodic inspection of apparatus, the renewal of oil in oil switches, emergency operating, etc., but time does not permit.

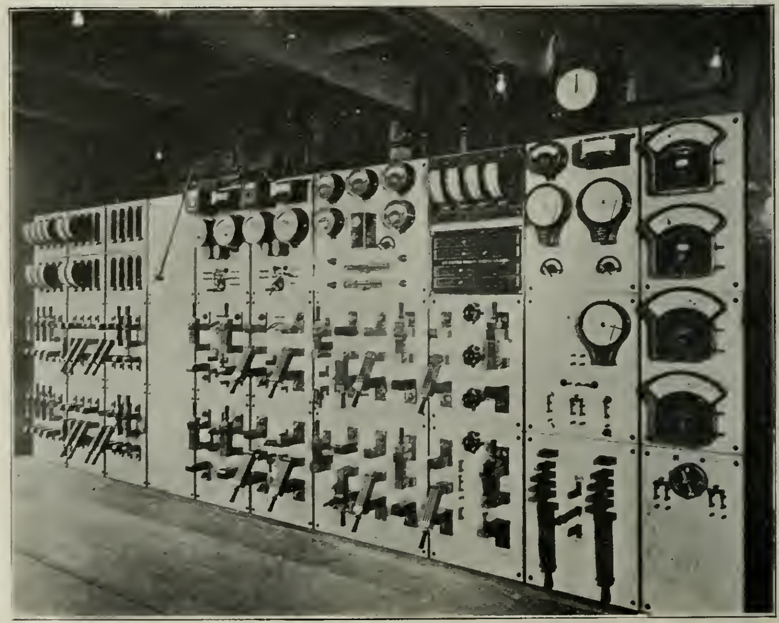


Fig. 20.

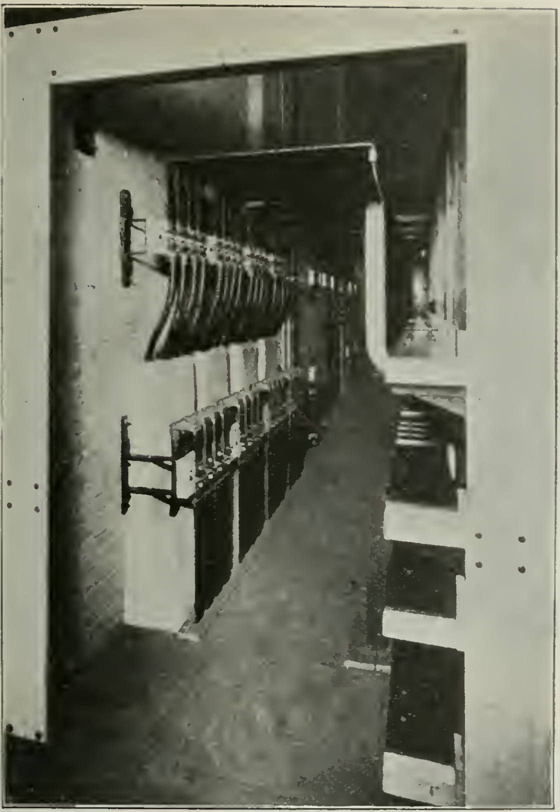


Fig. 21.

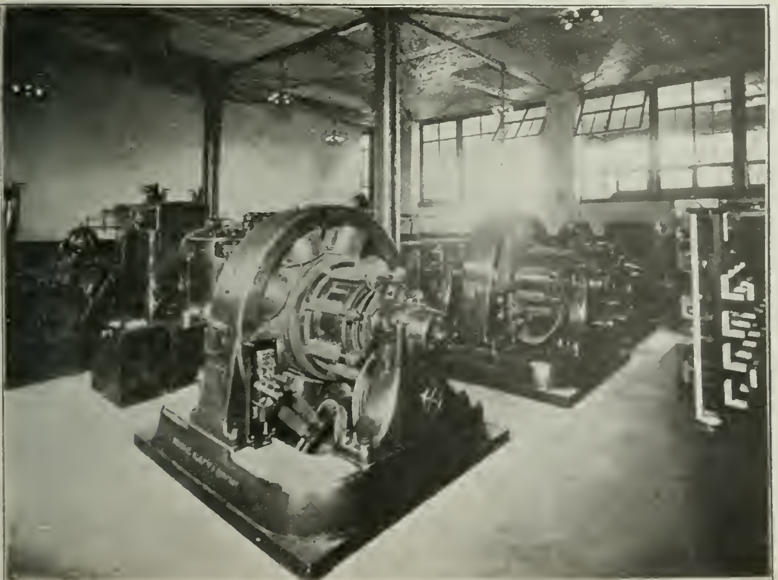


Fig. 22.

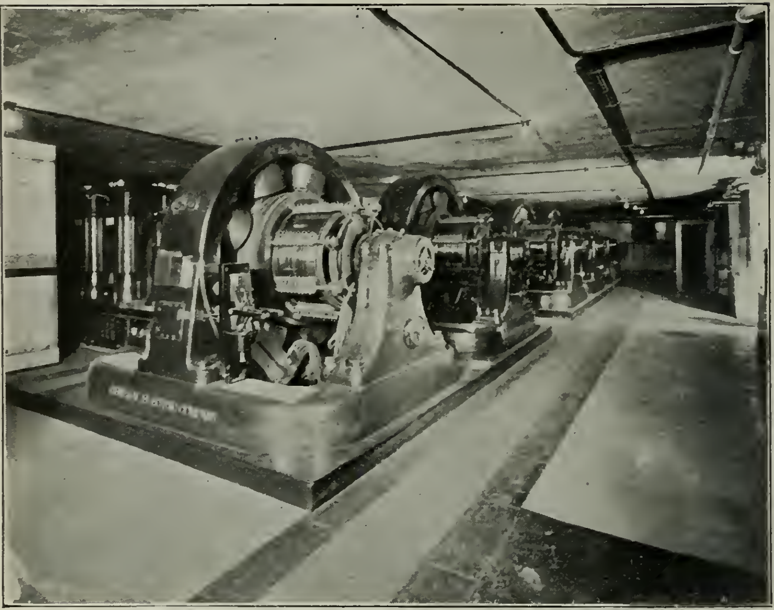


Fig. 23.

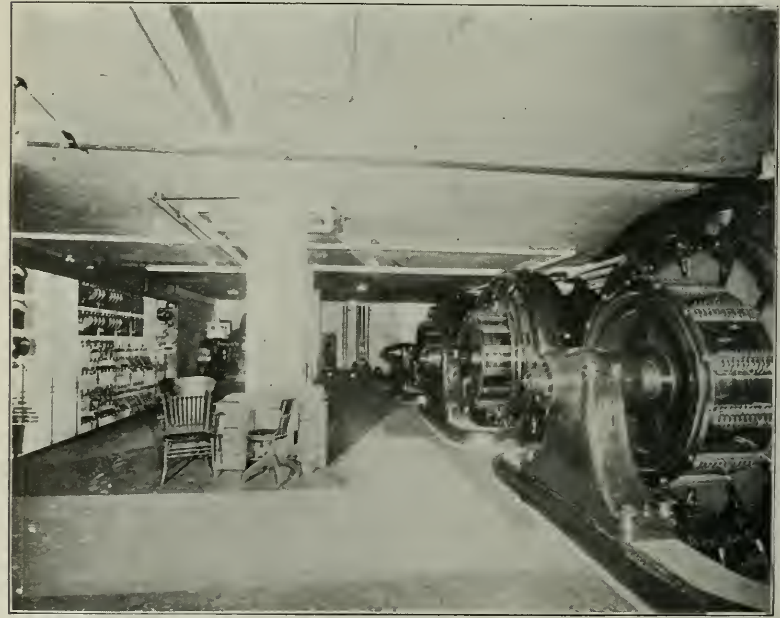


Fig. 24.

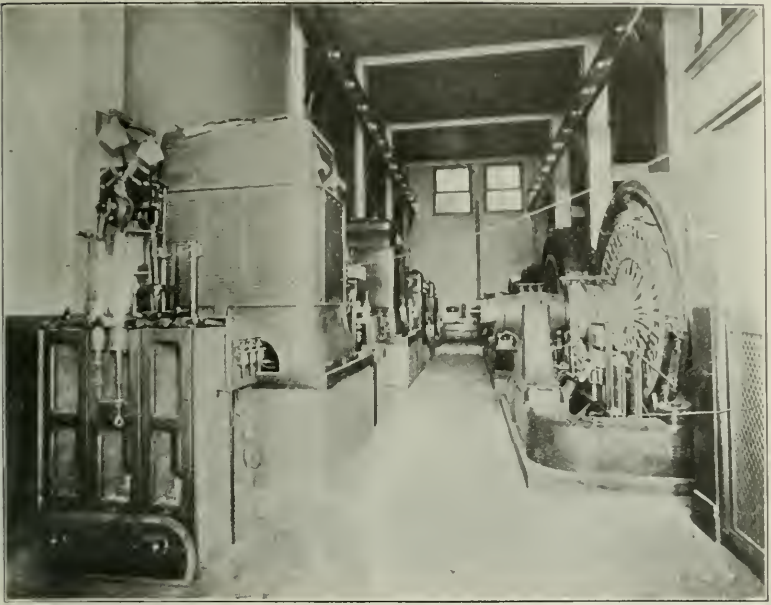


Fig. 25.

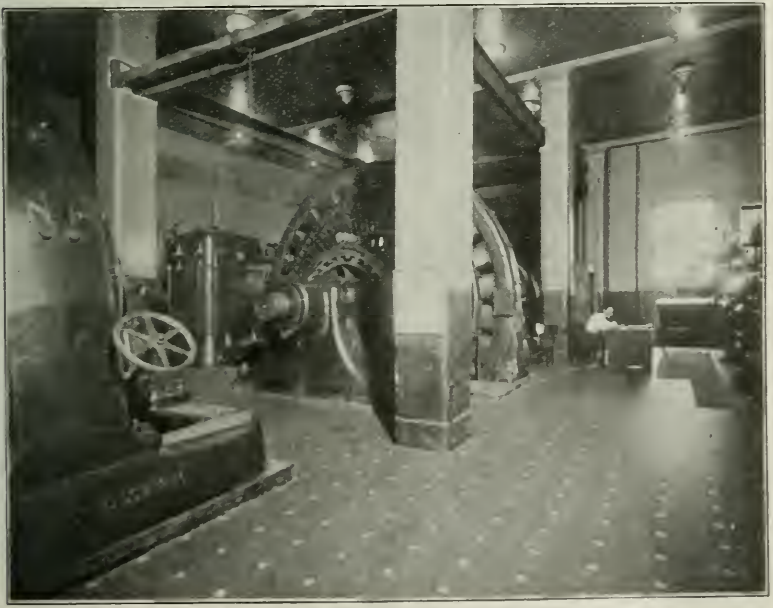


Fig. 26.

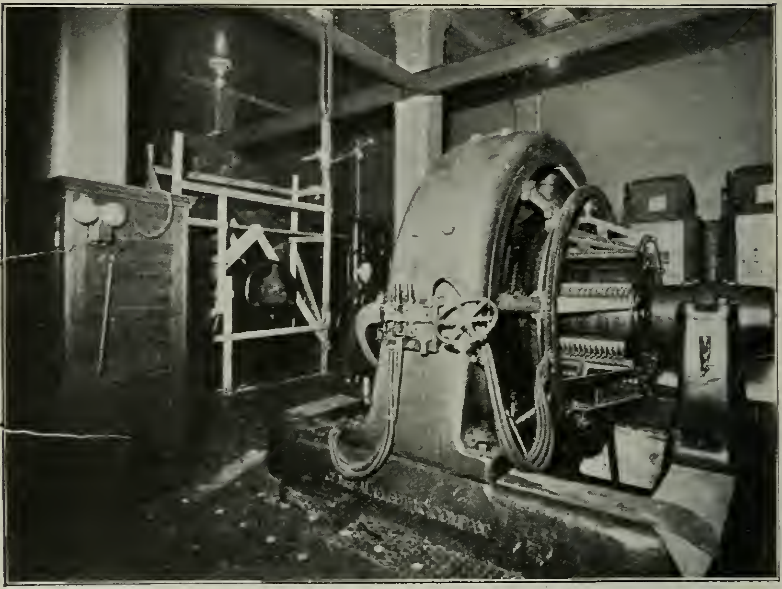


Fig. 27.

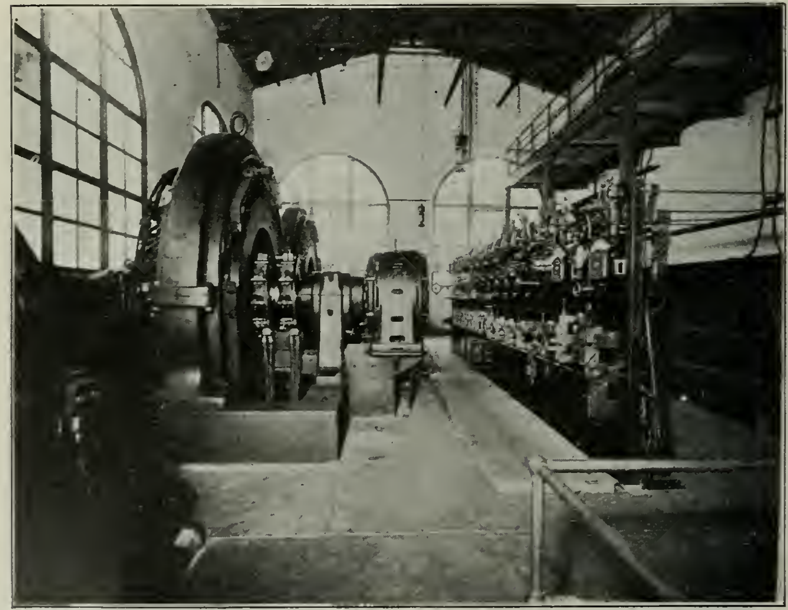


Fig. 28.

DISCUSSION.

Mr. E. F. Smith, M.W.S.E.: I have listened with great interest to all that the speaker of the evening has said, and I feel that we are greatly indebted to him for having given us an excellent address on an important subject. There is only one fault to find, and that is one creditable to the speaker. He has so thoroughly covered the subjects of the underlying theory of operation and constructional details of rotary-converter sub-stations that there is little left to be said by those of us who had intended discussing it. However, there are some practical points which have not been touched upon, a few of which may be of interest to operating men.

In connection with the maintenance of such sub-stations there are the subjects of brush economy, care and maintenance of commutators and collector rings, oil economy, maintenance of bearings, maintenance and care of blower and air cleaning equipment, care and maintenance of transformers and regulators, etc. In connection with the practical operation of such sub-stations the following points might be considered: Importance of accurate synchronizing, proper procedure to be followed in the regular shutting down of converters, procedure in starting up after a partial or general interruption of the 9000 volt system, etc. I shall refer briefly to each of these points.

The question of brush economy is one of extreme importance, especially when considered in connection with the operation of a large system, such as that of the Chicago Edison and Commonwealth Electric companies, of this city. In these systems there are in operation about 70 rotary-converters, and when we consider that the cost of a complete set of brushes for a rotary-converter ranges from $40.00 for a 500 kw. machine to $180.00 for a 2000 kw. machine, which means that the cost of brushes only, of the converters in operation in the system mentioned, is slightly in excess of $4.-000.00, it will be readily seen that brush economy is quite an important subject.

This matter has been given a good deal of careful study, and by careful attention to systematic maintenance of brushes, commutators, and collector rings, the life of a set of d. c. brushes has been increased until it is from four to five years at the present time. This figure includes wearing out and destruction of brushes from all causes, including the wear on commutator, sanding, cracking due to vibrations, explosions due to rapid expansion, and burning off of pigtails or unsweating of pigtail caps due to poor contact or defective distribution of load between brushes.

Considering wear and loss due to sanding only, the life of a d. c. brush is equivalent to about eight years, and considering wear only, the life would be about ten years for an a. c. copper brush and twenty years for a carbon brush. It will thus be seen that, considering twenty years as the maximum possible life and four years as the actual life obtained in practice, that the percentage of life in the Edison and Commonwealth systems is about 25%. This is considered to be comparatively high.

There are 430 brushes on a 2000 kw. machine and 112 on a 500 kw. machine, necessitating constant care and attention in order to keep them in prime condition. The matter of properly setting the brushes is of the utmost importance. The brush holder studs on the d. c. side should be accurately and equally spaced all around the commutator, and a line of brushes of a given polarity across the commutator should be absolutely parallel with the commutator bars. The positive brushes on the alternate positive studs should be staggered with reference to each other, so as to cover the entire commutator surface, instead of allowing the brushes of a given polarity to track and form grooves. This is especially important since it is found in practice that the passage of heavy currents from the commutator to the surface of the positive brushes removes copper from the commutator and deposits it on the faces of the brushes; and if all of the positive brushes are tracking or in line around the commutator, a series of grooves will soon be formed under each of the rows of positive brushes. This action is avoided if the setting referred to is adopted.

Experience indicates that a carbon brush tension of about 1.33 lb. per sq. in. gives most satisfactory service and contributes to the life of the brush and commutator. The copper brushes on the a. c. side give very satisfactory results when the tension per sq. in. of contact is from 1.5 lb. with a 500 kw. to 2 lb. with a 1000 or 2000 kw. unit.

The current density in the contact surface of the rotary-converter brushes in use in the system referred to, ranges from 27.6 amperes per sq. in. for a 500 kw. rotary to 33.3 amperes per sq. in. for a 2000 kw. rotary on the d. c. end, and from 50 to 57 amperes per sq. in. for the laminated copper brushes on the a. c. end. The equivalent of at least one complete row of carbon brushes are treated with dynamo oil and distributed in the brush holders about the commutator in such a manner as to bear on the entire commutator surface. This is for the purpose of effectively lubricating the commutator, thereby reducing friction and noise in operation. The method of treatment consists in immersing the carbon brushes in boiling oil for a period of about an hour, after which they are removed and dried at a temperature of 200° F. or 300° F. for a period of half an hour or more. The commutator surface is frequently wiped with a clean piece of cheesecloth, and when the machine is about to be shut down and is well heated up, a piece of cheesecloth bearing a trace of oil is wiped across the commutator, with a clean, dry piece of cheesecloth bearing upon the commutator, surface immediatey back of the oiled cloth. This method of maintenance will keep the commutator and brush surfaces in good condition.

The a. c. brushes are staggered on the ring, so as to get an even wear, and it is found with good care that it is not necessary to retrim them or seriously disturb their adjustment more frequently than about once a year. They are then properly trimmed and beveled and replaced on the machine. A very light application of vaseline or machine oil from time to time, while the machine is in operation, will effectively prevent cutting of the ring or excessive wear on the copper brushes. This treatment will preserve the commutator and collector rings in good condition, requiring the turning down of the collectors at intervals of about five years, and turning of the d. c. commutators at intervals of from five to ten years. As the cost of turning down commutators and collector rings ranges from $58.00 for a 500 kw. machine to $140.00 for a 2000 kw. machine, it will readily be seen that there is room for substantial saving by the proper care of these parts.

In conection with oil economy, statistics show that the average consumption of oil for each machine in the system during the past year has been 3.2 gallons. This is equivalent to a life of four years for the oil. The method of caring for bearings and economizing in oil is about as follows:

The temperature of the bearings is very closely observed with reference to the temperature of the surrounding air, and in all cases where the rise in temperature exceeds 15° C. the oil is promptly filtered and replaced in the bearings. This will usually result in lowering the temperature. If the temperature still remains high, the cause is further investigated and removed.

The average rise in temperature of all bearings in the Edison and Commonwealth systems at the present time is approximately 14° C., the minimum being about 7° C. A portable filter is used for the purpose of filtering the oil, and is sent from one sub-station to another as required.

It is extremely important that the condition of the blower equipment for the air blast transformers and regulators, be properly maintained at all times, as the shutting down of the blower would seriously affect the operation of the converter units at times of heavy load, and on account of the serious overheating of transformers and regulators which would follow, it would soon become necessary to shut down the main units if the air blast were not restored.

The screens used for cleaning the air are regularly inspected and washed and blown out, and the ventilating ducts of the transformers and regulators are thoroughly blown out and cleaned from once to twice a week.

In connection with the operation of such sub-stations, accurate synchronizing is about the most important specific operation required to be performed there. Any serious inaccuracy in performing this operation will result in fracturing the castings of the potential regulator, or if there is no regulator used in connection with the unit, the armature conductors of the converter are likely to be drawn out of their slots or the transformer structure seriously strained.

In connection with the regular shutting down of rotary-converters which are normally started from the d. c. end, it is extremely important that the field circuit of the converter should be left closed until the machine stops rotating. This is necessary in order to thoroughly demagnetize the transformer cores, and is particularly true in connection with diametrically connected units.

It will be seen that under certain conditions the converter may stop with the d. c. brushes resting on the commutator bars, which are connected to the same armature conductors to which the collector rings are connected, which are in turn connected to the terminals of a given transformer coil, thus placing this transformer coil in shunt circuit with the armature windings of the converter. If this transformer coil has been previously demagnetized, its impedence will be sufficient, upon throwing the starting current into the armature of the converter, to prevent an undue amount of current from passing through the transformer instead of through the armature of the converter, and the machine will start. However, if the transformer had not been previously demagnetized and the field circuit had been opened at a time when the magnetization of the transformer coil was at a maximum, in the same direction as would be caused by the passage of the starting current through the transformer coil, then there would be practically no impedence, and the practical equivalent of a short circuit would be connected to the d. c. brushes of the converter, thus rendering it impossible to start the machine. In this case the brushes should be lifted from the a. c. rings, and the transformer momentarily connected to the high tension line, thus changing its magnetic state to a more favorable condition.

In connection with starting up the system after a general shutdown, if the shut-down has been of such long duration as to result in fully discharging the storage batteries, thereby leaving many of the sub-stations without an adequate source of supply for starting from the d. c. end in the regular way, the procedure employed in some of the large systems is to start a large group of converters from a turbine or prime mover from rest, with low frequency, low voltage, multi-phase currents. The field circuits and d. c. switches of the converters are left open, and the unit is connected on the a. c. side only. A d. c. voltmeter is connected to the d. c. terminals of the machine, and as soon as the turbine begins to slowly rotate, slight vibrations of the voltmeter needle will be observed. This action will continue, gradually increasing in amplitude, until the rotary begins to turn. After the converter has made a few complete revolutions the voltmeter needle will have discontinued vibrating, and if the field circuit has not been closed at the proper instant, will have taken up a fixed position either above or below zero, indicating correct or incorrect polarity. The field circuit should be closed as the needle is swinging past zero in the direction of correct polarity, thus locking the converter into synchronism with the generator and insuring correct polarity if the operator is skillful in performing the operation.

The power factor is adjusted to unity by means of the field rheostat, and as soon as the converter potential is equal to the system potential, the d. c. switches of the converters are closed and other converters are started from the d. c. side. They are then synchronized with the low voltage, low frequency line, and other generators are synchronized under similar conditions at the power house. Another stage of acceleration then takes place, and this action is repeated until the entire system load has been raised to the normal d. c. potential.

In our operating practice covering this emergency procedure, machines of a rated capacity of 11,000 kw. have been thus started from rest, and machines of additional capacity of 7,500 kw. were immediately started, receiving direct current from them, after which they were synchronized with the low voltage, low frequency lines. Additional machines of a rated capacity of 11,500 kw. were thrown onto the line merely as a drag, making a total of 30,000 kw. connected to one turbine when the final stage of acceleration was started. As the turbine used was one of the older units, it is believed that with a new unit of greater capacity a much larger load could be brought up from rest.

In some of these trials, the time required to perform all operations from the time the converter started turning until the second converter had been started with d. c. received from the first, and synchronized and cut in with the low voltage, low frequency line, was as low as 30 sec.; the average time, however, is considerably higher.

The time required to start machines from d. c. end under regular conditions ranges from about 51 sec. for a 500 kw. machine to about 1 min. and 30 sec. with a 1000 kw. machine, not including time required for regulator operation. It is not often necessary to operate the regulator after a shut-down, but in case it should become so, under extreme conditions necessitating running from the neutral point, the time for a 500 kw. machine would be about 1 min. and 50 sec., and for a 1000 kw. converter about 2 min. and 27 sec.

Mr. C. A. S. Howlett, M.W.S.E.: I would ask Mr. Smith if he will advise us what kind of brush he used.

Mr. Smith: The Chicago Edison and Commonwealth Electric companies experimented with various brushes, without getting very satisfactory results. The one used at present is the standard pigtail carbon brush, made by the General Electric Co. We have trouble occasionally from the brush splitting, and frequently have cases where the distribution of load between the brushes is not perfect, thereby increasing the density in others, especially in the old type. In the new type there is an expanded thimble and the pigtail is connected to that part. They have not been in use long enough to enable us to form a thoroughly good idea of their comparative merits.

Mr. J. R. Cravath, M.W.S.E.: I would ask what progress has been made with the vertical shaft converter in this country?

Mr. P. Junkersfeld, M.W.S.E.: Thus far none of those machines have been completed. There are a number that will be delivered in the next six months. Briefly, the design of the vertical rotary converter, contrary to our ordinary conception of a vertical unit, is so arranged that the shaft does not revolve. In a vertical turbine the shaft revolves but in these vertical rotaries the shaft is stationary and is of considerable diameter.

There are two particular advantages expected from these rotaries. One is that they are accessible. You probably noticed in the view of the 2000 kw. 36 pole horizontal rotary that it was very high, requiring a man to go up on steps to get at the upper brushes; and to get at the lower brushes he has to get down into the pit, which is very inaccessible. The second advantage is that, for the same output the weight will be considerably less and hence should be somewhat cheaper. In the 2,000 kw. unit under construction the weight will be about 25 per cent. less than the weight of the 2,000 kw. machine shown on the screen tonight.

Mr. Howlett: I would ask Mr. Junkersfeld if he can give us any indication of what the ultimate outcome will be in this city?

Mr. Junkersfeld: The curve you saw showed an unusual recent increase, due to an enormous growth of the street railroad business. Of course there is not enough railroad business in Chicago to continue growing at that rate. I might say, however, that independent of this railway business, the central station business down town has increased at the rate of about 25 per cent, per year, but it will be some time yet before all the basements are filled up. About half of the present light and power demand is supplied from those rotary converters, and the rest is supplied by isolated plants. Only part of the rotary converters are located in basements, the remainder are in permanent sub-station buildings.

Mr. Roper: With reference to the ultimate situation, the distribution in the down town district indicates that in the future one sub-station will be able to supply all of the demand within the radius of a block or a block and a half, so we will only have to have rotary sub-stations on every other corner.

Mr. Ernest Lunn: The storage battery is necessary for the safety of a rotary converter system, as it is the only stand-by capacity that a rotary converter system has. The batteries are connected to the d. c. bus at all times ready to help out whenever needed. There is no law governing the proper ratio of storage battery capacity to generating capacity, for that is usually governed by local conditions, and also by the availability of sites suitable for battery sub-stations.

THE DEVELOPMENT AND OPERATION OF A LARGE ELECTRIC TRANSMISSION AND CONVERSION SYSTEM.

Ernest F. Smith, m.w.s.e.

Presented before the Electrical Section January 11 1907.

As the great systems of the Chicago Edison and Commonwealth Electric companies are thoroughly representative of the best modern practice in the large American cities of to-day, these systems will be particularly referred to as a basis of this discussion.

During the comparatively brief period of less than two decades the maximum load has increased from 313 kw. to 72,600 kw., and during the same period the connected load, expressed in equivalent 16 c. p. incandescent lamps, has increased from 20,000 in 1888 to 3,700,000 in December, 1906.

Eighteen years ago one small steam plant was employed in carrying the maximum load of 300 kw., whereas at the present time neither that plant nor any of the several small steam plants subsequently installed, is in operation, but practically the entire load, ranging from 60,000 to 70,000 kw., is carried by two large plants, one of which was first put in commercial operation only three years ago and is now carrying 54,000 kw., or 77 per cent of the entire load of both systems.

The system of the early days comprised a low-tension, three-wire "Edison Tube" underground network, receiving energy through underground tube feeders directly from the bus bars of the several small steam plants, which were operated in parallel through the network of underground mains. There was also a large number of d. c. series arc and single-phase high frequency a. c. and 500-volt d. c. power circuits, supplied by numerous small belted units ranging in capacity from 12 to 90 kw. The greater part of the energy supplied to the low-tension, three-wire system was generated at the old "Adams Street station" at 139 Adams street by means of a large number of small Edison bi-polar dynamos belted to high speed engines, located on the floor below the generators. The high-tension load was carried at the "Washington Street station" at Washington street and the Chicago river, the engines being on the first floor, driving by rope transmission three jack shafts on the third floor, to which were belted a great number of small dynamos located on the second floor. The incandescent lighting and power loads in the outlying districts, beyond the economical range of the three-wire, low-tension system of distribution, were supplied from this station through the 125-cycle, 1000-volt and the 500-volt d. c. power circuits, respectively.

In 1894, or about six years after the first generating station at

139 Adams street was put into commercial operation, the maximum load had increased to 5,700 kw., and the station had outlived its period of usefulness. It had become obsolete and seriously overloaded, and as there was no available space for further extensions, a large modern central station was built on the west bank of the Chicago river at Harrison street. The equipment in this plant consisted of ten vertical triple-expansion "Southwark" engines directly connected to twenty multi-polar General Electric 150-volt generators; each engine driving a generator on each end of its shaft. Twelve of these generators were of 400 kw. capacity each, and the remaining eight were each of half that capacity. The two generators of each unit were connected in series, with a neutral tap between the machines, to provide for operation in the well known manner on the three-wire system. This station began operation in 1894, and the Adams Street station was shut down and dismantled.

As the site of the Adams Street station was retained for the center of distribution for the down-town network, a mammoth underground trunk line, 66,000,000 circ. mils in cross sectional area and 3,400 ft. in length, was installed between the new Harrison street generating station and the distributing center, at 139 Adams street. This center of distribution was located in the basement and constituted the first sub-station in the system. The twenty d. c. generators at the Harrison Street station delivered their output to the main bus bars in the Adams Street sub-station through the trunk line just referred to, and from these bus bars low-tension direct current was supplied to a large number of three-wire D. C. underground feeders, radiating in all directions and feeding into various points of the underground three-wire network through Edison junction boxes at the street intersections. These feeders were, of course, provided with switches, ammeters, etc., in the sub-station, and ranged in size from 150,000 to 750,000 circ. mils for the positive and negative conductors and about one-third the section of the outers for the neutral conductor. They were of the Edison Tube type, and all of the larger sizes are still in service. The underground mains and services were also of Edison Tube at that time.

In 1891 a small generating station was built at Twenty-seventh street and Wabash avenue to supply low-tension direct current to the South Side three-wire underground system. A small series-arc load was also carried by this station for a few years. Two years later a small modern low-tension station was put in service at North Clark and Oak streets, for the purpose of feeding the north side underground three-wire system. There were four generating units in this station, each consisting of a vertical, cross-compound, non-condensing "Lake Erie" engine directly connected to two 75 kw., 150-volt d. c. generators. At about this time submarine cables were laid across the bed of the river at Fifth avenue, Clark and State streets, connecting the north side and down-town systems together, thus rendering the low-tension underground system one vast interconnected network, extending from North avenue, on the north, to Thirty-ninth street, on the south. Subsequently this system was extended to the west side, and some of the small high-tension machines at Washington street were replaced by belt-driven, pi-polar, Edison low-tension d. c. generators. There were then four widely separated d. c. generating stations, with numerous units operating in parallel in each, and all working together in multiple, directly feeding the one system of interconnected underground low-tension mains.

Soon the low-tension underground system was extended into the territory supplied by the 500-volt power, the series-arc, and the 1000-volt 125-cycle circuits from Washington Street station, and all of the 500-volt customers were then changed over to the new system. All old open series-arc lamps within the territory of the new system were also exchanged for low-tension multiple lamps. This resulted in throwing out of service many of the old high-tension machines, and modern direct-connected low-tension D. C. generating sets were installed in their stead at the Washington Street station. It was not possible to economically reach the distant outlying high-tension load, however, with the existing system of distribution of low-tension direct current supplied direct by the generating stations. The load on the latter system continued to grow rapidly, and the territory to be supplied quickly expanded during the three years succeeding the starting of the new Harrison Street station, which was at that time the largest and finest central station west of New York.

The maximum load increased to 8,800 kw. in 1897, and it had become apparent that the system of direct distribution from the d. c. generating stations was entirely inadequate to economically provide for future development. This year (1897) marked the dawn of the most important epoch in the history of the development of the great systems under discussion, as the *rotary-converter* was produced at about this critical time, and the first machines were installed and put into operation here in Chicago during that year.

The essential purpose of the converters is to enable the use of high-tension, alternating, multi-phase currents, for economical transmission of energy, from the generating stations to the distant centers of d. c. distribution. As the radius of economical distribution by the old direct method was scarcely more than two-thirds of a mile, and as the d. c. system had grown to a length of approximately six miles, with a breadth of about one mile, it will readily be seen that the continued use of the old system of distribution would have necessitated the installation of numerous small generating stations throughout the territory served by the three-wire d. c. system. The operation of these numerous small plants would have involved great loss of efficiency in the generation of energy as compared with the high economy now realized by the centralization of power generation, with very large units in essentially one mammoth power house, which has been rendered practicable only through the use of the rotary-converter and the motor-generator.

Of equal importance, from a financial view point, is the great saving in investment per kw. of capacity in favor of the modern system. The inception of the modern system in Chicago, as already stated, occurred in 1897, when three rotary-converters were first put into commercial service. The parent machines consisted of two 3-phase, 100 kw., 125-volt and one 3-phase, 250 kw., 250-volt converters, and, after some preliminary trials, they were adapted to the existing low-tension d. c. three-wire system in the following manner:

The rotary-converter, consists essentially of a d. c. generator with equidistant taps taken out of the armature winding from the end opposite the commutator, and connected to the collector or slip rings mounted on the shaft. Single-phase converters have two such taps; three-phase, three taps; and six-phase, six taps per pair of poles. If the commutator end of the converter be supplied with direct current, the machine will operate in the same manner as any ordinary d. c. motor; and if a pulley were provided upon the shaft, the machine could be satisfactorily used as a d. c. motor. On the other hand, if the collector rings of the machine be properly fed with alternating currents of the frequency, voltage, and phase for which it is designed, it will operate as a synchronous a. c. motor and will satisfactorily drive a mechanical load as such. Again, if a prime mover or any primary source of mechanical power be connected to a converter and the latter be driven by the same, the converter will generate and deliver both direct and alternating currents simultaneously at the d. c. and a. c. brushes, respectively. The full rated output as a generator may be taken either as direct or alternating current, or any proportion of either may be taken from the machine so long as its total capacity rating, expressed in amperes, when operating as a generator, is not exceeded. When operated as a generator, however, the rated load for a given temperature rise is considerably less than when the same machine is operated as a converter, by reason of the fact that the current in the armature, when operating as a generator, must flow through the entire armature winding, whereas when operating as a converter, part of the current from the source of supply, passes into the armature at one end and directly out through the nearest tap at the other end.

As a rotary-converter the machine may be operated directly or inverted, i. e., if alternating current be supplied to the collector rings, direct current will be delivered at the d. c. brushes, and *vice versa,* if direct current be supplied to the d. c. brushes, the converter will deliver alternating current at the collector rings. Herein lies the essential feature of the performance of a rotary-converter, which enables it to bridge the gap between an alternating current and a direct current system.

The limited radius of economical transmission by the low-tension

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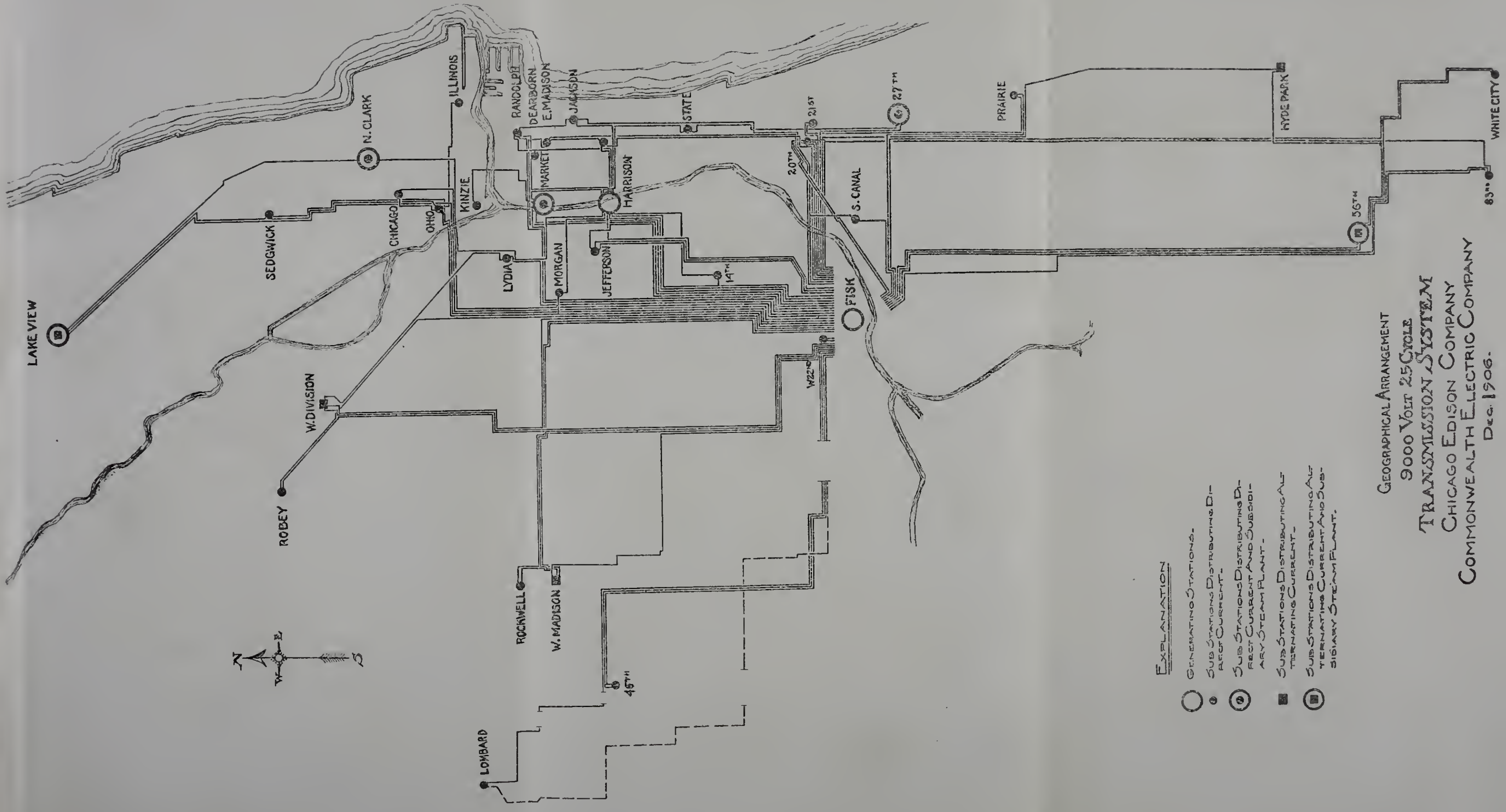


Geographical Arrangement
9000 Volt 25 Cycle
Transmission System
Chicago Edison Company
Commonwealth Electric Company
Dec. 1906.

multiple d. c. system already referred to results, of course, from the following conditions:

The transmission voltage being only 250 volts, approximately, the current in amperes for a given kw. load is comparatively large, and as the allowable loss in d. c. voltage at say 10 per cent. is only 25 volts, the necessary size or cross-sectional area and consequent weight of the feeder increases very rapidly and soon becomes prohibitive in cost for large loads, distributed over very limited areas. Hence it becomes necessary to utilize high pressures and correspondingly low currents for the purpose of economically transmitting large quantities of energy from the power house to the distant centers of low-tension distribution.

On account of the great facility and efficiency with which alternating currents may be transformed from a low to a high potential, and *vice versa,* this form of electrical energy is far better adapted to transmission purposes than is high-tension direct current, and the alternating current is, therefore, universally used in connection with long transmissions. Furthermore, 3-phase alternating currents are used in preference to single-phase current, as a given amount of power can be transmitted a given distance at a given transmission voltage with 25 per cent. less copper, and this saving represents thousands of dollars in a large transmission system.

As a rough example of the saving which may be effected in copper by the use of a 3-phase, 9000-volt alternating current transmission system as compared with a 3-wire, 125-250 volt direct transmission to distant local centers of d. c. distribution, it is interesting to note that, with an average length of transmission line of four miles and a transmission of 75,000 kw. delivered at 5 per cent. line loss and unity power factor, the amount of current per phase would be approximately 5,350 amperes and the weight of copper would be approximately 223 tons. The corresponding figures with the low-tension 3-wire system, with one-third section for neutral conductor, would be 333,300 amperes per side, requiring 448,351 tons of copper. Hence the weight and cost of the copper would be 2,010 times as great with the latter system, and at 20 cents a pound the extra cost of copper would amount to $179,250,000. Of course, the four-mile low-tension feeders would not be used, but the necessity of installing numerous small steam plants throughout the d. c. system, in order to shorten the d. c. feeders, would involve excessive costs both in investment for equipment, buildings, etc., and in operating expenses.

Thus we see clearly the great advantages possessed by the 3-phase high tension a. c. system of transmission.

As a rotary-converter will operate inverted, it may be used to supply an a. c. transmission line through step-up transformers if its d. c. leads be connected to a suitable source of direct current. At the other end of the transmission line one or more converters may be supplied with alternating current through step-down static transformers and potential regulators, and the converter will deliver low-tension direct current.

It was in this manner that the first converters already referred to were put in operation in Chicago. The 250 kw. converter was supplied with direct current from the main bus in the Harrison street generating station, and the low-tension 25-cycle, 3-phase alternating current delivered by the converter was passed through a potential regulator to the primary coils of three delta-connected static transformers. By means of these transformers the potential was raised to about 2,250 volts, and the 3-phase currents were transmitted through a 3-conductor No. 0 underground cable to the station at Twenty-seventh street and Wabash avenue, a distance of about three miles. At this station the high tension current was passed through three delta-connected transformers, which reduced the potential to approximately 85 volts between phases and delivered 3-phase, 25-cycle current through potential regulators to each of the 100 kw. converters. These converters delivered direct current at approximately 125 volts, and as they were connected in series with the neutral lead tapped to the series connection, their output was available for supplying the existing 125-250 volt, 3-wire d. c. system. Thus the 250 kw. inverted converter in the Harrison Street station became the father of the great transmission and conversion system of to-day, and it is an interesting fact that this old obsolete machine is still hard at work in the Twenty-first street sub-station, operating in parallel with two modern 6-phase converters, delivering direct current to an important part of the south side system.

The new system immediately demonstrated its efficiency and adaptability to existing conditions, and was rapidly extended. However, as there are various hazards and objectionable features associated with the operation of inverted rotary-converters, it soon became necessary to provide additional capacity in a more reliable and economical form for the purpose of supplying the A. C. transmission system. To accomplish this, four of the 200 kw. direct current generators at Harrison street were reconstructed and thereby converted into double-current generators directly connected to two 600 H. P. triple expansion engines. These machines were in effect rotary-converters directly connected to steam engines, and when driven by the engines were capable of generating both direct current and 3-phase, 25-cycle, low tension alternating current at the same time. The full rated load of 400 kw. in either kind of output could be carried by each unit. This was especially advantageous at that time, for the following reasons:

As the daily maximum load occurred about three hours earlier down town than in the outlying residence districts, these machines were worked at their full capacity as d. c. generators, delivering current directly through low tension feeders to the down-town d. c. system during the peak of the load, which occurred at about five o'clock in the afternoon. As the down-town load dropped off rapidly after 5 o'clock, the load on the double-current generators was shifted over to the a. c. transmission system. As the d. c. load on the double-current generators became lighter, they were thus gradually loaded up on the a. c. side to supply the a. c. transmission system until about eight o'clock in the evening, when they were working at full capacity, carrying a portion of the peak load of the residence district. Thus the same generating units were continued in use in the old system and were also made available as an additional source of supply for the new system, without having installed additional generating machinery for the latter purpose.

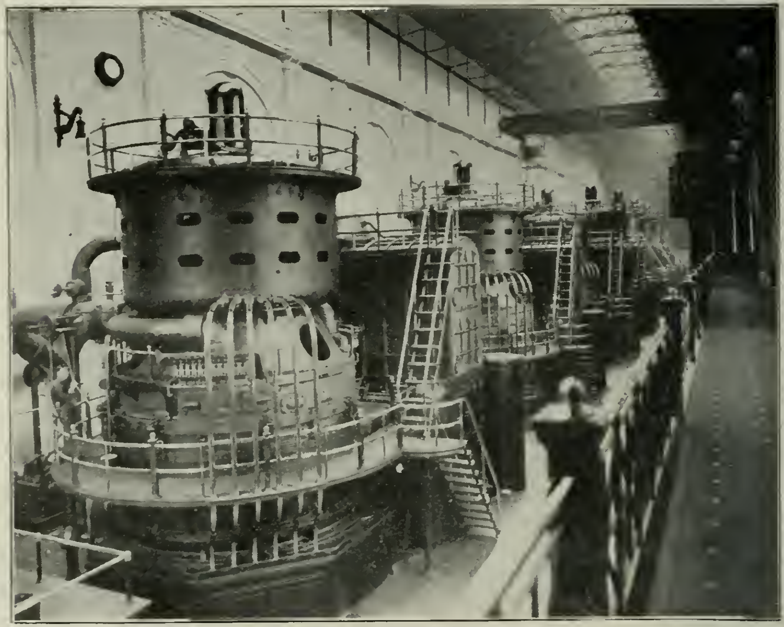
The next unit installed at the Harrison street station was a 2500 kw. double-current generator, designed to be used on both systems in the manner just described. This generator differed from the two small units in that it delivered 300-volt direct current and 6-phase alternating current. The speed of this machine is 75 rev. per min. and as there are 40 poles, the frequency is 25 cycles per second. Two banks of three delta-connected, 450 kw. air blast static transformers are used to raise the low tension a. c. voltage to that of the transmission system, which, by the way, was increased from 4,500 to 9,000 volts some time before this unit was put into service. The original 2250 volts had been doubled within a year after it was started. All units subsequently installed at the Harrison street station were designed to deliver 3-phase, 25-cycle, 9000-volt current at the generator terminals, and their rated capacities were as follows: Two 1000 kw., one 1800 kw., and one 3500 kw. The addition of these units increased the rated capacity of the station to 16,200 kw., of which 5600 kw. was in direct current, 7300 kw. in alternating current, and 3300 kw. in combination d. c. and a. c. generators.

During the year 1900, two years after the Commonwealth Electric Co. commenced business, a modern 3-phase, 4-wire, a. c. central station was put in operation adjoining the old series-arc plant at Firty-sixth and Wallace streets. The loads of six small generating stations in the southern district were transferred to this station, and a high-tension 60-cycle center of distribution, known as the Hyde Park sub-station, was also established at Fiftieth Place and Cottage Grove avenue. This sub-station received current over two 4-wire, 4150-2400 volt, 60-cycle transmission lines from the Fifty-sixth street station, and distributed it to the surrounding territory through numerous single-phase and 4-wire, 3-phase, 60-cycle circuits. The single-phase lighting circuits and the lighting phases of the combined 4-wire, 3-phase power and lighting circuits were all provided with potential regulators for the purpose of independently controlling the potential at the end of each feeder. The 4-wire circuits carried a combined lighting and power load, with the lighting load connected between the respective phase wires and the neutral wire, and the power load connected between the 3-phase conductors.

The generators at the Fifty-sixth street station are star connected, with the neutral lead brought out from the common point, thus giving the A, B, and C phase conductors and the neutral or fourth wire, which is permanently connected to ground. This system of 4-wire, 3-phase, 60-cycle, 4150-2400-volt distribution superseded the old single-phase, 125-cycle 1000-volt system, and has since been extended throughout the city in the outlying districts, where the density of the load is not sufficient to warrant the use of the 3-wire d. c. system.

Three generating units were installed in the Fifty-sixth street station, aggregating 2400 kw. in capacity, and there have since been installed three motor-generators of a total capacity of 2500 kw. Each of these motor-generator units consists of a 9000-volt, 3-phase 25-cycle motor directly connected to a 4150-2400 volt, 3-phase, 4-wire, 60-cycle generator. The motors receive current through under ground transmission lines from the 9000 volt generators at the power house several miles away, and the generators to which the motors are connected are operated in parallel with each other and with the local engine-driven generators.

In the fall of 1903, or about nine years after the Harrison street station was first put in operation, the system load had increased to approximately 33,000 kw., and although the d. c. generating capacity at the Washington street station had been increased to 4500 kw. and storage batteries of a one-hour capacity of 10,200 kw. had been installed, there was scarcely sufficient capacity to provide for



Turbo-Generators, Fisk Street Station.

the load. At this juncture the first giant turbo-generator in the new generating station at Fisk street on the Chicago river was put in operation, and from that time up to this date the rapid extension of that station has with difficulty kept pace with the demands made upon it by the constantly increasing load. Within a year after this station started the system load had increased from 33,000 to 39,600 kw., a year later to 53,800 kw., and this year the maximum load was 72,600 kw.

Although the Fisk street station is only three years old, there are, at the present time, eight, 3-phase, 25-cycle, 9000-volt turbo-generators in operation in this station of an aggregate overload capacity of about 86,000 kw., with sufficient room for extension to provide for an additional overload capacity of 72,000 kw. It is interesting to note that the capacity of one unit at Fisk street today is sufficient to carry as much load as was carried by the entire systems of both companies only eight years ago. Each of the largest units at Fisk street has an overload capacity of approximately 12,000 kw., corresponding to 16,000 electrical H. P. or 240,000 standard 16 c. p. lamps for a limited period of time.

The 25-cycle system is operated in two independent sections, each feeding a large group of sub-stations through underground transmission lines. The 25-cycle generators in the Harrison street station are operated in parallel with one section of the Fisk street station through three, 3-conductor, 4/0 underground tie lines 14,000 feet in length. There are upwards of fifty transmission lines, aggregating about 230 miles in length. The size of conductors in these transmission lines ranges from No. 0 to 250,000 circ. mils. Each line is protected by overload time limit relays, and consists of a paper-insulated, lead-covered cable drawn into a vitrified clay conduit, through manholes spaced about 500 feet apart. The high tension cables are thoroughly protected against mechanical injury and fire by an envelope of split tile in all manholes and in stations and sub-stations between the building wall and the oil switches. Each sub-station is provided with one or more transmission lines direct from the power house and a tie line to an adjacent sub-station. These tie lines between sub-stations are ordinarily kept open, in order to minimize complications at times of serious disturbances due to grounds or short circuits on the transmission system. Each such tie line is available, however, as a source of supply through another sub-station in case the direct lines are out of commission for any reason.

In all cases where it is practicable to do so, the two direct lines to each sub-station are carried over different routes, in order to prevent trouble on one of the lines, being directly communicated to the other and thus totally interrupting the supply. For instance, such lines are carried through different tunnels under the river and are also run through separate conduit systems where possible.

Three years ago, when the Fisk street station began operation, there were twenty-three sub-stations in the system, having a total rated capacity of 33,000 kw. The equipment in some of these sub-stations consisted exclusively of rotary-converter units; others of frequency changing motor-generator units; others contained storage batteries only, and still others included all of the various types of equipment. The total rated capacities of the various kinds of equipment were as follows: Rotary-converters, 18,600 kw.; motor-generators, 4500 kw., and storage batteries at the 1-hour rate of discharge, 10,200 kw.

At the present time there are thirty-two Edison and Commonwealth sub-stations, the total rated capacity of all of which is 79,695 kw., or nearly two and one-half times as great as that of only three years ago. There are now installed in these sub-stations 70 rotary-converters, ranging in capacity from 100 to 2000 kw. each; 19 frequency changing motor-generator sets, ranging from 250 to 2000 kw. each, and 20 storage batteries, ranging in capacity from 260 to 1425 kw each, at the 1-hour rate of discharge. In addition to these sub-stations there are eight railway sub-stations, operating 20 rotaries of a total rated capacity of 25,200 kw. One of the largest converters now in use is capable of carrying, under overload conditions, the equivalent of 60,000-16 c. p. lamps, and this is equal to the entire capacity of all the generating stations of both companies as they existed fourteen years ago, shortly preceding the opening of the World's Columbian Exposition.

All of the converting machinery in use at the present time is of General Electric manufacture, and all storage batteries were manufactured by the Electric Storage Battery Co., of Philadelphia. Owing to the high price of real estate and other existing conditions in the down town district, six of the nine down town sub-stations are located in leased basements, which have been reconstructed and refitted for the purpose. The principal difficulty encountered in adapting such premises to the purpose is, of course, the fixed condition of limited head room, thus seriously limiting the size of machines which may be installed therein. This is a very serious matter, both from the standpoint of necessary investment per kilowatt of capacity and of increased operating expenses. The remaining three down town sub-stations are in buildings owned by the company, and are known as the "Adams street," "Market street" and "Plymouth Place" sub-stations.

The Adams street sub-station, which has already been referred to as the down town terminus of the great Harrison street trunk line and as an important center of low-tension distribution, is also distinguished by reason of its containing one of the largest storage battery installations in the world. There are in this sub-station three large batteries, comprising from 150 to 160 cells each, each cell containing from 81 Type H plates in the smallest to 87 H plates in the largest battery. All of the plates of each polarity in each cell are connected in parallel, in order to increase the current capacity, and all cells are connected in series to obtain the requisite potential for use in connection with operating the batteries in parallel with Harrison street station and with neighboring sub-stations on the 3-wire, low tension system. The capacity of each of these batteries is 11,400 amperes at the 1-hour rate of discharge, or a total of 33,800 amperes for all three batteries at a maximum sustained potential of approximately 130 volts. At the middle point of the entire series of cells of each battery a heavy neutral lead is tapped off and connected through a switch to the neutral bus bar of the sub-station. It will be seen that with a 150-cell battery, this arrangement provides a maximum of 75 cells for use on each side of the 3-wire system. However, as the voltage per cell varies from about 2.5 immediately preceding the completion of charge to approximately 1.6 when discharged at the 1-hour rate to the limit imposed by the specifications, and as the sub-station bus pressure varies in accordance with the form of the load curve, it is, of course, necessary to provide a satisfactory means of regulating the difference of potential between the neutral and the working terminals of each side of each of the batteries.

This may be accomplished either by the use of "boosters" connected in series between the battery and the bus, or by means of end cells and corresponding end cell switches on each leg of each battery. The end cell method of regulation is used by the Chicago companies except in some of the railway sub-stations, where automatically controlled boosters are employed. In the end cell method the final 20 to 25 cells in the series on each side of the neutral are used as end cells in the well known manner.

The lead from each end cell is connected at one end to the cell and at the other end to its corresponding point on the end cell switch. The end cell switches are located in an end cell switch room adjoining the battery room, as near to the end cells as possible, and consists of a traveling laminated copper brush, one end of which is constantly in sliding contact with a heavy copper bar and the other end in sliding contact with one end cell terminal. Thus it will be observed that the number of cells in circuit at any given time is dependent on the position of the end cell switch, and that by moving the switch from point to point any desired number of cells may be included in or excluded from the circuit. The traveling brush of each end cell switch is mounted upon a fixed square-threaded screw, which may be rotated through worm gearing by means of a small electric motor controlled from the switchboard in the operating room. By means of a cam mechanism mounted on the shaft of the switch, the circuit feeding the motor is automatically opened and a magnetic brake applied at the instant when the travel of the switch from one point to the next has been completed. By means of a reversing control switch the motor and, therefore, the end cell switch may be run in either direction, one cell at a time, with a pause on each point, or continuously without stop from the lowest to the highest end cell by merely keeping the control switch button depressed instead of permitting it to spring out, as is done when only a single cell is cut in or out. It has no doubt occured to some of you that it would not be allowable or practicable to open the battery circuit each time the end cell switch moved from one cell terminal to the next. Neither would it be safe to allow the main laminated brush face to make contact with two cell terminals at the same time, as this would produce a short circuit with a flow of thousands of amperes through it, thereby destroying the switch, the leads, and probably the cell itself. In order to get around this difficulty the switch is so designed that in moving from one point to the next a small auxiliary advance carbon brush makes contact with one point just before the main brush loses contact with the other point. The auxiliary carbon brush and the main laminated copper brush are connected together through high resistance carbon or other suitable material, and a short circuit is thus prevented while the brushes are in contact with both points, and at the same time the amount of resistance between the brushes is so designed that the passage of the main current through it for the brief interval required will not seriously overheat it or drop the voltage. However, it occasionally happens that the motor stops with the switch in a position between points, on account of the blowing of a fuse in the motor circuit or some other cause. In such case it is necessary to immediately uncouple the motor from the switch and operate the switch by hand until it is making contact with a single point only. If this is not done immediately, the switch will be wholly or partially destroyed.

The copper bar referred to, with which the end cell switch brush constantly makes contact, is connected through heavy cables or bar copper to a switch on the switchboard in the operating room, and by means of this switch the end cell switch lead can be connected to either of the three buses, *i. e.*, to the main bus, the auxiliary bus, or to the charge bus. There are three such end cell switches connected in multiple to each leg, positive and negative, of each of the three batteries in the Adams Street sub-station. Hence, all three batteries with all three end cell switches may be operated in parallel on either of the three buses, or any one of the batteries may be operated on all three buses at the same time, carrying widely different potentials on each bus by regulating the position of each of the end cell switches independently of the others. As all low tension feeders are connected to double-throw switches and can be connected to either the main or the auxiliary bus, it is possible to carry the long, heavily loaded feeders on the auxiliary bus at a much higher voltage than that of the main bus, receiving current from the battery for the purpose. The principal and most important feature of the service expected from the batteries, however, is to cut off the daily peak of the load during the winter season and to stand ever ready, without a moment's notice, to discharge its full capacity into the system in case of emergencies seriously affecting the operation of the generating stations and consequently that of the rotary-converters in the sub-station.

Under conditions of former times the use of the battery for peak load service was generally regarded with favor, as the cost per kilowatt per battery for such short periods of discharge was considerably less than the investment required for the same maximum capacity in the form of steam plant and generating machinery, which was required to carry load only a few weeks in the year and for only a few hours per day during such time. Under present conditions, in large systems, however, the investment per kilowatt in generating plant is such that, combined with the deteriorating effect upon the battery believed to be produced by heavy peak service, the advisability of using the storage battery for peak service, more than is absolutely necessary, is seriously questioned. Thus it appears that the great function of the storage battery under existing conditions is to stand by, ready for immediate service in case of any contingency affecting the operation of the generating stations.

In order to be instantly, and largely automatically, available, it is the practice in all of the Edison systems of the large cities to float all of the storage batteries on the system at all times when not charging or discharging. The operation of floating a storage battery consists in connecting it to the system with just a sufficient number of cells in circuit to give a terminal pressure approximately equal to the voltage on the system, and as the system voltage gradually rises and later falls off during the daily cycle of load changes, to follow these changes by including and excluding cells from circuit, so that at the end of a given inactive period, although the battery had been constantly connected to the system, it shall have received as much energy from the system as it has discharged into the system during the numerous momentary fluctuations of the load.

Under these conditions the battery renders valuable service in steadying the system potential, and is ready to relieve the generating stations or pick up their load in case of trouble. As soon as such emergency occurs the battery automatically picks up a certain amount of load, corresponding to the seriousness of the trouble (the more serious the trouble, the heavier the load which will be automatically picked up), and then the operator in charge immediately cuts in as many end cells as are necessary to throw the approved amount of load onto the battery. After the emergency is past the battery is withdrawn from active service by the reverse operation of cutting end cells out of circuit by the system of remote control of the end cell switch in the manner already described.

In order that a storage battery may be charged under all of the conditions which are encountered in regular practice, it is necessary that an ample source of electrical energy be available in the form of direct current, the potential of which may be conveniently regulated and raised to a maximum corresponding to the voltage of all of the cells in series just before completing the charge plus the fall of potential through the battery due to the charging current. This form of energy for battery charging in the sub-stations of the Chicago Edison Co. is derived from the 9000 volt, 3-phase energy as received from the distant generating stations, by two entirely different methods, one of which is much more economical and direct than the other.

The more direct method involves the using of a special high voltage rotary-converter unit, which receives energy from the a. c. transmission line and delivers direct current direct to the battery through a special charging bus. The high potential required is obstained by the use of an extraordinarily large potential regulator and also a 3-phase to 6-phase reducing static transformer, the ratio of transformation of which may be changed by means of a double-throw switch connected to terminals and taps of the secondary coils. By means of these switches the unit may be used for ordinary regular service in parallel with other machines carrying system load or for high voltage service in charging storage batteries, etc. There are two such units in service in Chicago at the present time, one at the Plymouth Place sub-station and the other at the Market Street sub-station of the Chicago Edison Co.

The other method of charging requires the use of a booster set in each sub-station, the purpose of which is to receive direct current from the regular main bus and deliver direct current of higher potential to the charging bus. These machines consist of three units. all mounted on the same shaft, *i. e.,* a 250 volt d. c. motor mounted in the middle and a 0 to 70 volt d. c. booster generator on each end of the shaft. From one or more rotary-converters in operation, carrying the sub-station load, the booster motor receives direct current from the main bus and drives the direct-connected shunt wound booster generators. By means of field rheostats the voltage of each of the booster generators may be independently regulated, and when charging, the positive booster is connected in series between the positive bus and the positive lead of the battery through the charging bus, the end cell switch lead, the end cell switch, and the end cell copper to the highest cell in the series included in the charging circuit. The current entering through the positive terminal of this cell passes through all of the positive cells to the neutral point, and from this point the balanced portion of the charge current continues on through all of the negative series of cells up to that particular end cell copper whose terminal is in contact with the charging end cell switch, through which it passes on to the negative charging bus, thence to the positive terminal of the negative booster generator, and through the armature of the booster to the negative main bus, back to the rotary-converters whence it came.

There are three principal methods of determining when a battery is fully charged. They are, by observation of the pressure of a fixed number of main series cells, by observation of specific gravity of electrolyte of a standard cell, and by observation of gasing or violent evolution of gas bubbles and acid fumes rising from the cells when fully charged. It is well to make careful and systematic observations upon all of these characteristics in connection with the operation of a storage battery, but experience here in Chicago has indicated that the use of the first method referred to gives satisfactory results. By this method a recording voltmeter is connected across the greater number or all of the main series cells on each side of the battery. During discharge the line traced by the recording voltmeter gradually falls until the discharge is removed, when, if it be removed suddenly, the curve rises sharply, but not to its former level. When the charge is started the line rises at a rapid rate at once, on account of the drop through the battery, and as the charge progresses the line continues on upward, until suddenly the curve traced by the pen will round over, forming a knee in the curve. Very soon after this occurs the curve will become fixed in height, indicating that the voltage has discontinued rising, and at this point the battery should be gasing freely and ordinarily the charge should be discontinued. However, at frequent regular intervals the charge is allowed to continue on for an additional period of from thirty minutes to an hour, for the purpose of maintaining the plates in proper condition.

The aggregate rated capacity at the 1-hour rate of all of the storage batteries in the system at the present time is 17,700 kw., the equivalent of power required to light 354,000 16 c. p. lamps and more than equal to the load of the entire system only six years ago. Under ordinary conditions the batteries are floated on the system, except during the peak period, when they are discharged if necessary. Their principal value, however, resides in their immediate availability for meeting emergencies affecting the operation of the generating stations or the transmission system.

Referring to the rotary-converters, it may be of interest to note that each of the earlier units consisted of a 3-phase converter receiving current through a 3-phase induction potential regulator from three separate step-down transformers, with the primary and secondary windings, connected in delta, whereas each of the modern converter installations comprises a 6-phase rotary receiving a. c. supply through a 6-phase induction regulator from a single 3-phase to 6-phase step-down static transformer connected in delta on the 9000 volt side, with secondaries diametrically connected and tied together at their neutral points. From the common point a neutral lead is brought out and passed through a switch to the main neutral d. c. bus bar of the sub-station. Under normal operating conditions this scheme of connections tends to maintain an equal pressure on each side of the d. c. bus, automatically picks up the neutral current of the load and distributes it through the secondary coils of the transformer, back to the common a. c. and d. c. winding of the converter armature.

In case it becomes necessary to maintain a considerable difference of voltage between the positive and neutral bus and the negative and neutral bus, in order to maintain an equal voltage on each side of the d. c. feeder ends, then either the positive or the negative armature switches of the converter are opened, thus leaving the converter connected only to that side of the system which requires a higher potential. Under these conditions 6-phase alternating current flows between the secondaries of the transformer and the collector rings of the converter through the potential regulator As there is but a single winding on the converter armature, part of this current flows directly through the winding to the commutator, thence through the positive brushes and positive lead to the positive bus (provided the positive armature switch is closed and the negative open; *vice versa* otherwise). In the former case, direct current flows from the positive bus out to the positive mains through the positive feeders. thence through the positive mains to the positive building services, through the positive services to the positive load, and the unbalanced portion then returns through the neutral services, mains and feeders to the neutral bus bar in the sub-station. It then passes through the neutral lead to the common neutral point of the secondary coils of the step-down transformer, and is distributed therein as already stated.

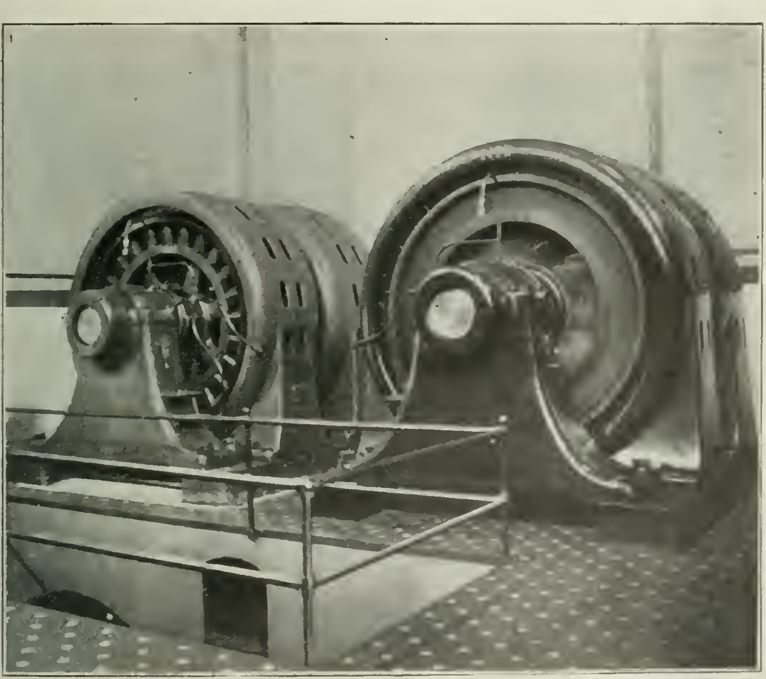
The 3-unit booster sets in combined rotary and battery sub-stations are also used as balancers, by connecting the two 70-volt generators in series and operating them on either side of the system. The generators are driven by the direct-connected motor, which receives current from the positive and negative d. c. buses.

In other sub-stations the old 125-volt rotaries are used to carry the neutral load, and in one sub-station a 2-unit balancer set is in operation. This unit consists of two 115-volt d. c. generators, the armatures of which are mounted on the same shaft, and are connected in series. The shunt field of the positive machine receives excitation from the negative bus, and the negative field is supplied from the positive bus. The neutral bus is connected to the series connection between machines. When in operation the machines are thus connected in series between the positive and negative buses, with the neutral bus connected to a point between the machines. Under these conditions the unit is largely automatic in its action, as a rise in voltage on the positive bus strengthens the field of the negative machine and causes the positive machine to act as a motor and drive the negative machine as a generator, thus tending to lower the voltage on the positive side and raise it on the negative side, at the same time transferring load from one side of the system to the other. The reverse action occurs in case the voltage falls on the other side of the system. The action of the balancer may also be controlled by hand, by means of field rheostats connected in circuit with the shunt field coils.

When we consider that the unbalanced load of each small branch circuit is neutralized in the risers of each building; that the unbalanced load in the risers is again equalized in the building service wires; that the unbalanced load of the various buildings in a block is again neutralized in the neutral conductor of the underground main; that the unbalanced load of all the mains radiating from each junction box at the street intersections is neutralized in the neutral bar of each box, and that the net unbalanced current flowing in the feeders is again finally neutralized in the main neutral bus bar of each sub-station, it may be readily seen that so long as the load of the entire system is reasonably well balanced, there will be but very little neutral current to be carried by the balancing machines in the sub-stations. As an interesting example, one of the largest down-town sub-stations, carrying a total load of 25,000 amperes, seldom carries more than 200 amperes neutral current, which is equivalent to about 0.8 of 1 per cent. of the load on the outer conductors.

As the more important features of construction and operation of rotary converter units were fully described by Mr. Schuchardt in his excellent paper recently read before this Society, I shall not make further reference to that subject at this time.

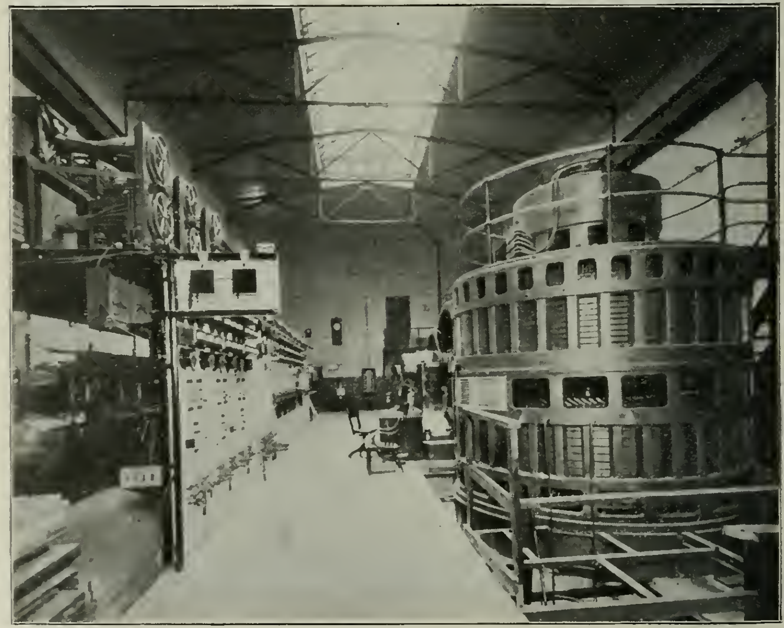
The output of the d. c. sub-stations is carried to the under-ground mains through lead-covered, paper-insulated cables, ranging in size



25 to 60 Cycle Frequency Changers

from 250,000 to 2,000,000 circ. mils. The standard feeder consists of a 1,000,000 circ. mil. concentric cable, carrying pressure wires which are connected to the rings or bars of the feeder junction boxes at one end and to a multiple-point voltmeter switch at the other end in the sub-station. By means of this switch a pair of potential indicators can be connected to any set of pressure wires, thus indicating the pressure at the system end of any feeder. The pressure at the end of the standard feeder is maintained at a certain figure by regulating the load on the converters in operation or by cutting in or out converters as required. In the largest sub-station as many as nine converters are frequently in operation in parallel at the same time.

A brief description of the installation and operation of frequency changing motor-generator units may be of interest. The nominal capacity of the nineteen units of this type in Chicago ranges from 500 kw. to 2000 kw. each, as previously stated. Each of these units, excepting the 2000 kw. machines, is of the horizontal revolving field type, with a 25-cycle motor and a 60-cycle generator mounted on the same shaft. The 2000 kw. units are similar to the other machines, with the important exception that the shaft is vertical with two guide bearings and a step bearing, the latter being supplied with oil at a pressure of approximately 500 lbs. per sq. in. As the



2000 kw, Vertical Frequency Changer.

frequency of the three-phase current received from the transmission system is 25 cycles per second, and as this frequency is too low to be successfully employed in connection with lighting service, it becomes necessary to change the frequency from 25 cycles to one sufficiently high for lighting purposes. The frequency employed in the Commonwealth system is 60 cycles, and the essential purpose of the motor-generator units under discussion is to perform this conversion of frequency and voltage from 25-cycle, 9000-volt, 3-phase to 60-cycle, 4150-2400 volt, 4-wire, 3-phase energy. Current from the 25-cycle transmission system is supplied to the 9000-volt bus bars through remote controlled Form H3 General Electric Co.'s oil switches. From these bus bars energy is delivered to the stationary armatures of the 9000-volt, 3-phase synchronous motors through remote controlled type K General Electric Co.'s oil switches. These motors each drive a 60-cycle, 4-wire, 3-phase generator mounted on its shaft. The fourth or neutral conductor of each generator is permanently connected to the 60-cycle neutral bus bar, and the 3-phase conductors can be connected to either of two sets of 60-cycle buses through remote controlled type K oil switches.

These bus bars supply energy to the various single-phase and combined 4-wire, 3-phase lighting and power circuits, radiating in all directions from each of the 60-cycle sub-stations. Adjacent 60-cycle sub-stations, receiving energy from the same 25-cycle system, are operated in parallel when desired, through 4150-2400 volt, 4-wire tie lines. Provision is made for operating all of the frequency changing units in each sub-station in parallel on both the 25-cycle and 60-cycle sides, and they are so operated under ordinary conditions.

In each of the modern 60-cycle sub-stations there are three sets of 60-cycle bus bars, and the switching arrangements are such that each generator and each circuit can be connected to either of two sets of buses through remote controlled oil switches. An electrical interlocking system is employed in connection with the oil switch control circuits, to provide against connecting a circuit or generator to two buses which are not in synchronism and in phase.

The revolving fields of the horizontal motor-generators are supplied with direct current from induction motor-driven, compound-wound, multipolar generators, ranging in capacity from 50 kw. to 75 kw. each. The vertical 2000 kw. units are provided with a 100 kw. compound-wound d. c. machine, the armature of which is mounted on the top of the vertical shaft. This d. c. machine is used as a motor for starting the unit, and as an exciter after the 9000-volt motor is connected to and running in synchronism with the generators at the power house.

The horizontal units are started in the following manner: A starting compensator, consisting of an auto-transformer, is connected through an oil switch to the 9000-volt bus and to the starting bus. The compensator delivers 3-phase current at about 2700 volts

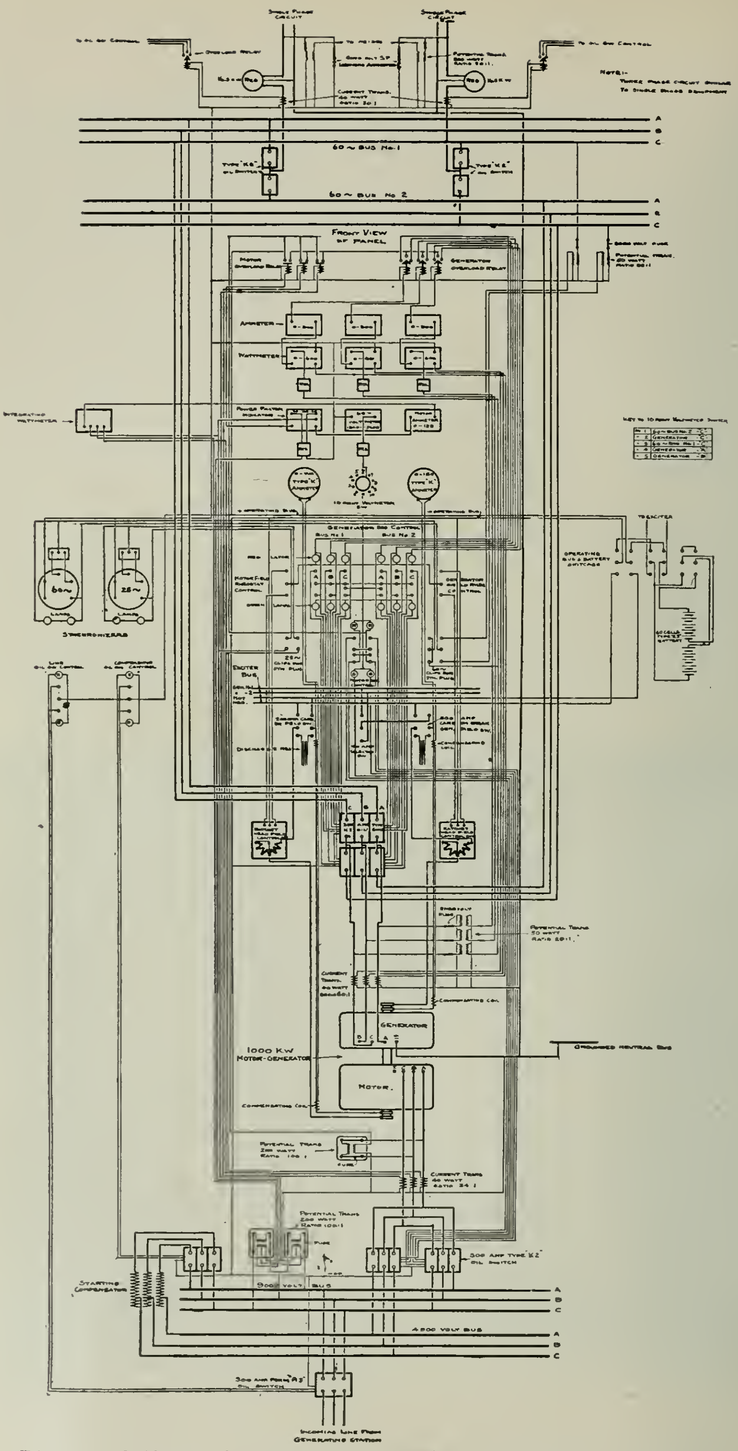


Diagram of Electrical Connections of 25-60 Cycle Frequency Changing Motor-Generator Unit, to the starting bus, to which the motor to be started is connected through a remote controlled oil switch. With the field circuit of the motor open, it will start in a manner similar to that of an induction motor under similar circumstances. As soon as the motor is up to speed its fields are excited, and it is disconnected from the starting bus and immediately connected to the 9000-volt bus. The field rheostat of the motor is then adjusted to obtain unity power factor. after which the fields of the generator are excited and the generator synchronizing circuits closed, to determine whether the incoming generator is in phase with those already connected to the 60-cycle bus and carrying load. As the motor has five pairs of poles and the generator has twelve pairs, there is only one out of the possible five conditions in which the motor may be running in synchronism with the transmission system which will correspond to the proper phase position of the generator with reference to the other generators already in operation. That is, if the incoming generator does not happen to be in phase with the other generators, it becomes necessary to slip the synchronous motor back one pair, two pairs, three pairs, or four pairs of poles, as indicated by the 60-cycle synchronizer.

This operation is performed in the following manner: The motor is disconnected from the 9000-volt bus by means of its remote controlled oil switch, and as soon as disconnected its speed will commence to fall, causing the 25-cycle synchronizer hand to gradually move away from the point indicating synchronism between the motor and the transmission system. When the synchronizer hand has made one complete revolution and at the instant synchronism is again indicated, the motor oil switch is closed, thus again locking the motor in synchronism with the line. This operation is repeated as many times as necessary (never more than four times) to bring the generator in phase with the generators in operation. The potential of the incoming generator is then properly adjusted, after which it is connected in parallel with those already in operation, by closing its remote controlled K oil switch. The incoming generator will automatically pick up its share of the kilowatt load, but the proper division of the ampere load requires careful manipulation of the field rheostats of all the generators connected in parallel, in order to avoid excessive cross currents immediately after the incoming generator is cut in.

The procedure employed in putting the 2000 kw. units in service is similar in many respects, the essential difference consisting in the fact that the machine is brought up to speed by means of the 100 kw. d. c. machine directly connected to the top of the shaft of the principal machine. After the revolving element, which weighs 80,000 pounds, has been accelerated to synchronous speed the 25-cycle motor is connected to the starting bus, the motor fields closed, etc., etc., in the manner already described. The synchronous speed of these machines is 300 rev. per min.

All of the induction motor-driven exciter units are protected by overload relays connected to current transformers in the high tension, 3-phase leads, in the same manner as for motor-generator and rotary-converter units. These exciter relays are set to act at about 300 per cent. overload, the high setting being adopted to guard against losing excitation except in case of extremely serious trouble in the exciter unit, requiring that it be immediately and automatically disconnected from the 9000-volt bus.

In the large 60-cycle sub-stations there are several exciter sets, all of which can be operated in parallel on the d. c. exciter buses, or each may be operated independently on one of three sets of d. c. buses. The essential purpose of the several exciter buses is to provide for the automatic regulation of the terminal voltage of the generator by means of a Tirrill regulator. Through a system of

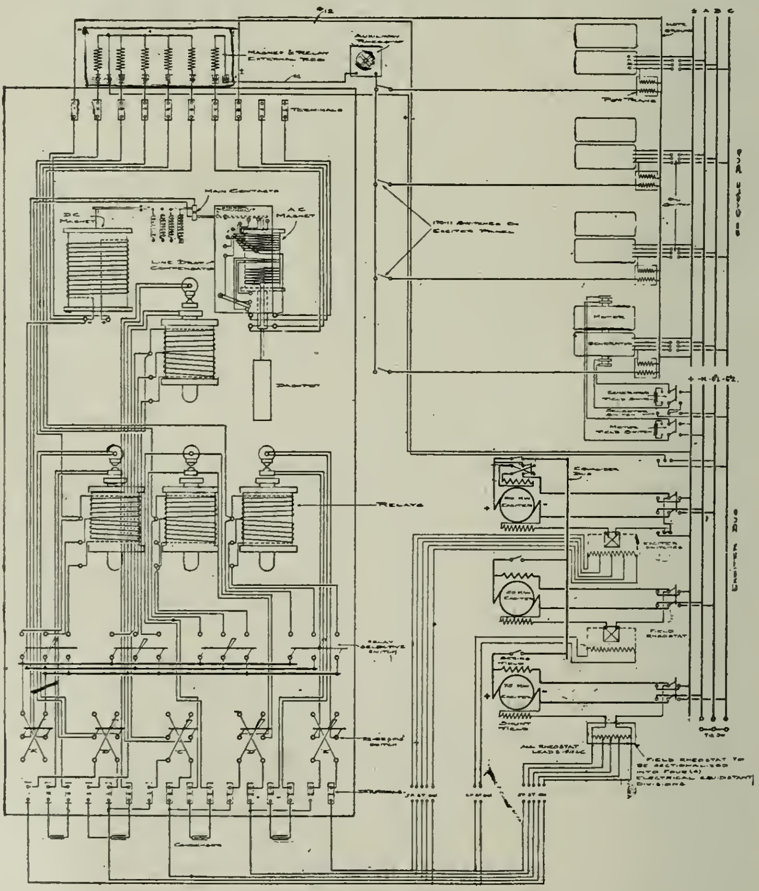


Diagram of Electrical Connections of Tirrill Automatic Regulator,

a. c., d. c., and differential relays and solenoids the Tirrill regulator at frequent intervals short circuits the rheostat in the shunt field circuit of the exciter which is supplying the field current of the 60-cycle generators, which are under the control of the automatic regulator. The short circuiting of the exciter rheostat has the effect of increasing the voltage on the d. c. exciter bus, and this in turn increases the field excitation of the 60-cycle generators, thereby increasing the voltage of the 60-cycle bus to which they are connected.

In order to increase the range of action of the Tirrill regulator, the field rheostats of the 60-cycle generators are all cut out while under the control of the regulator. Under these conditions, if the exciter rheostat were to be permanently short circuited, the exciter voltage would promptly build up to its maximum value and remain there, causing the voltage of the 60-cycle generators to rise to the highest value which they are capable of delivering, and to remain at that value, affected only by changes in load. Now, if the short circuit across the exciter rheostat were permanently removed, thereby including in its field circuit all of the resistance in the rheostat, its d. c. voltage would fall to a minimum, as would also that of the generators, thus delivering a very low voltage to the 60-cycle bus bars. It will readily be seen that the terminal voltage of the 60-cycle generators between these extreme limits may be controlled at will by intermittently retaining the short circuit across the exciter rheostat during a definite percentage of time, corresponding to each definite voltage within the limits referred to. The Tirrill regulator automatically controls the frequency and duration of the short circuits across the exciter rheostat. With every heavy 60-cycle load swing the regulator will instantly short circuit the exciter rheostat, and this short circuit will continue until the 60-cycle bus pressure is up to standard, when the intermittent action of automatically removing and replacing the short circuit will continue at a constant frequency and duration of contact until the next change of 60-cycle load occurs. In case of a reduction in the 60-cycle load, the regulator action is the reverse of that just described.

The regulator can be adjusted to automatically maintain a constant standard voltage on the 60-cycle buses, or to deliver a uniformly increasing voltage with increasing load. At least two exciter sets are required in connection with the operation of motor-generators controlled by a Tirrill regulator, as the voltage applied to the generator fields is necessarily variable, while that applied to the motor fields must be more nearly constant in order to maintain unity power factor. Therefore, at least one exciter must be independently operated on the generator exciter bus bars, while another must be independently hand regulated and connected to the motor fields through the motor exciter bus.

The remaining or third exciter bus previously referred to may be used to excite one or more generators not subject to the control of the Terrill regulator.

Each of the 60-cycle circuits are equipped with remote controlled regulators, some of which are automatic in their action, thereby maintaining a constant voltage at the center of distribution of the circuit at all times, regardless of the variable load on the circuit. Formerly pressure wires were connected to the center of distribution of each 60-cycle circuit, and run back to the station, where they were connected to a voltmeter, the indications of which were used as a guide in regulating the pressure applied to the station end of the feeder, so as to maintain a constant voltage at the system end. In all modern practice, no such pressure wires are used, but the circuit voltmeter is caused to indicate the potential at the end of the circuit through the medium of a line drop compensator for each circuit, located in the same sub-station. This line drop compensator is essentially a miniature artificial circuit, possessing all of the characteristics of resistance and reactance of the circuit to which it is connected. Current derived from a series transformer, connected in the 60-cycle circuit, is passed through this artificial circuit, and the drop through same effects the indications of the voltmeter, which receives current from a potential transformer and through the artificial circuit.

The automatic 60-cycle circuit regulators referred to are actuated through relays, which are in turn automatically governed by the line drop compensators in a manner similar to that described in connection with the compensated voltmeter.

In conclusion, it need be said that this whole subject has been treated in a largely superficial manner, by reason of the necessarily limited time available for its presentation during a single evening. Any one of the various features of construction or operation referred to might well be made the subject of a paper, but in preparing a general treatment of the whole subject it was hoped that it would be of more general interest than would have been the case if some special feature had been adhered to as the subject of the discussion.

DISCUSSION.

Mr. D. W. Roper—M.W.S.E.—Mr. Smith, in his paper, has told a great many things in regard to the development, growth and operation of a large system. There is, however, one feature in connection with such a system to which he has not referred, and that is the human element involved. The man who designs the machinery, the mechanic who builds it, as well as the engineer and draughtsmen who lay out the sub-station and produce complicated wiring diagrams, the workmen who install the machinery, the men who install and connect the distribution system, all have an opportunity to perform their respective duties. If each one is skillful, diligent and faithful in his part, then we have a complete distributing system, and the public secures an uninterrupted and unvarying supply of current for its purposes. If, however, any of those who were employed in designing or constructing the system are neglectful or careless in their part, interruptions to the service will occur. At each interruption the pessimist is inclined to hail it as another example of the frailty of human nature, the greed of graft, etc., but those who are familiar with some of the difficulties to be overcome would be more inclined to look upon the absence of such interruptions as the proof of the integrity of human nature. It is only by cooperation of all those involved in the design, construction and operation of such a system that the desired results can be produced, and in comparing the results of several systems, that system is most successful which can deliver the current to its customers with the greatest steadiness, with the fewest interruptions, and the largest dividends to the stockholders.

Mr. H. R. King—M.W.S.E.—I have listened to Mr. Smith's paper with a great deal of interest, and am sure I have been very much benefited. One thing that impressed me greatly was the comparatively short time in which this magnificent system has been developed. It is practically within the time of the memory of all of us that this development has taken place. It has been one from a system of comparatively simple design and operation, having the individual switches operated directly by the attendant and not by the remote control mechanisms, and using no protective devices (which were probably not needed) to a complicated system, to the uninitiated, requiring numerous protective devices, and great skill in operating. As Mr. Roper has said, the human element must necessarily enter greatly into its successful operation. In looking back over this rapid development we cannot but wonder what the future has in store for us. We see from the paper tonight that the development has been from the ordinary reciprocating engine to the steam turbine, having higher efficiency, less floor space, and more uniform operation. In the future we may see more complicated developments, attended with a more complicated plant arrangement. The gas engine is coming into use, and it has great claims.

The development during the next ten years of large power plants, such as we have had described tonight, will be watched with interest, and no doubt a paper on this subject at that time will be full of surprise when considered from our present view point.

Mr. C. A. S. Howlett—M.W.S.E.—Mr. King touched on a point that was in my mind. My work is more along the lines of Sales Engineer than purely technical engineering, and I want to bring out the fact that when an organization can develop its business in from eight to ten years from 300 kw. to 70,000 kw., there is some opportunity for good business men as well as engineers. I do not think engineers have developed in the same ratio. I say this for the benefit of some who are looking at the commercial end of this work.

Mr. E. F. Bracken—One of the most interesting subjects is the 60-cycle system. By referring to the first map shown on the screen you will notice that the little inclosure within the heavy lines in the down-town district does not comprise more than 0.1 of the area of the whole city. In other words, the low tension district is only a small part of the city. All the rest of the city which is supplied at all is supplied by a. c. current, 60-cycle system. While the load in that district is not as great as the low tension load, there are a larger number of customers, and the number of profitable customers in that district makes it very important that the system should be kept up in good shape.

These sub-stations in that field are somewhat in the shape of a crescent. In other words, if we would draw roughly a crescent around the outside, we would pass through all the six sub-stations. They are all located rather closely to the low tension district, but that is on account of convenience of transmission, and they supply a great area, by means of 3-phase 4-wire system. The sub-stations are equipped with three different kinds of units, and the total capacity is 14,500 kw., and there is to be another one of 2,000 kw. These stations are all tied together, so arranged that we could parallel all the six stations at one time if desired, or could until quite recently. This made it possible to transmit current from one station to another. While we can parallel motor generators on the same bus, they are not capable of dividing their kw. load except in fixed ratios. It is possible to divide the current load nicely, shift load from one to the other, and run one at a high power factor and the other at less power factor if wished. The machines are always paralleled on the 60-cycle end, after they are in phase with the 25-cycle system, and the necessity of getting them actually in phase means that it is necessary to take special pains to see that they do not develop any cross current. It will not do to have the fields keyed on a shaft at random. If one should lead the other in phase, then this machine would pick up more than its share of the load. If one leads a little they cannot be operated in parallel satisfactorily. When machines are to be paralleled they may be differently phased by as much as 20, 30 or 40 deg., a machine already in operation being held back by the load. However, as soon as the machines are paralleled, the kw. load is distributed in proper proportion and this difference in phase no longer exists.

The machines, as pointed out, have a very elaborate system of protection; this is also extended to the circuit. It is generally intended that the circuit should open up rather than that the machine should shut down.

Mr. P. Junkersfeld—M.W.S.E.—This is a subject in which I have been much interested for a good many years, and for about twelve years I have been closely associated with work along that line.

I want to make one correction in connection with the remarks made by Mr. Howlett. The system has not grown quite as fast as he had in mind. It is eighteen years instead of eight years in which it grew from 300 to 70,000 kw.

Mr. Roper has touched on the most important thing that comes up in connection with any large undertaking or engineering development. From the time of the earliest conception of the machine, so much thought has to be given all along the line, and so many different kinds of labor enters into the work, that a final result which will be the best obtainable is a very difficult matter. In a large manufacturing establishment, such a machine in its course from concept to finished product probably passes through a dozen different departments, and heads and sub-heads,—men who contribute a vital and essential part to the success of that machine. Both before and after the machine leaves the manufacturing establishment, the designing engineers, the people who lay out the station, and the people who operate the station, must all contribute conscientious and enthusiastic effort.

The City of Chicago might be said to be fan-shaped; everybody wants to go to or from State and Madison streets and at the same time. The lighting and power load in that vicinity is the most dense and it tapers off as we get away from that point. The real dense area is less than one square mile; then the area covered by direct current distribution is 15 to 18 square miles; and then, beyond that, is another area or "third zone," of something like 120 or 130 miles, which is already fairly well covered by a. c. distribution.

If Chicago is going to grow in the manner predicted by people who have given the subject thought,—grow to a point where it will reach 5,000,000 population and within the lives of most of us here—many changes will have to be brought about and many greater developments. The systems already laid out will undoubtedly answer very well (barring *unusual* developments, of course), for many years; but if Chicago is going to reach 5,000,000 population, some of our present surrounding prairies will have to become populated, and they will demand light and power; this would result in a "fourth zone." Experience thus far indicates that 20 to 25 thousand volts transmission underground is feasible and successful. At this time we are seriously considering a higher voltage underground transmission for this "fourth zone," and in fact have started on one installation where we will have 20,000 volts. So while work has begun along definite lines, there are a great many problems ahead of us, and a great many more will come up within a few years.

Mr. R. F. Schuchardt—M.W.S.E.—There is one point that occurs to me in connection with this paper, and Mr. Smith just hinted at this when he said that those two pigmy rotaries at the Twenty-seventh Street sub-station are still operating and giving excellent satisfaction. It is of interest to note that the development in electrical machinery during the period mentioned in Mr. Smith's paper is largely of increase in size rather than improvement in electrical design. Machines built even earlier than those rotaries are still in operation, and are of fairly good efficiency considering their size. There have been some improvements in iron used for electrical purposes, but the men who designed the early dynamos built wisely and well. This is illustrated nicely by the original bi-polars of Edison, which have a capacity of some 60 lights. These units compare very favorably in efficiency with units of the same capacity built in recent times.

The development, then, in size is very interesting to trace. Starting out we have these 60 light machines in about 1879; jumping to the time the Harrison Street station was started, we find the then famous "white elephant" of some 1200 H. P., and now we have at Fisk Street station units of nearly 20,000 H. P. maximum capacity. These latter impress us all the more when we remember that in 1893 the immense E. P. Allis engine exhibited at the World's Fair was rated at just 2000 H. P.

Mr. King—I would ask if any figures have ever been gotten up as to the percentage of increase in capacity of Edison plants, as related to the percentage of increase in population of the city of Chicago? For instance, when we have arrived at 5,000,000 population, about what H. P. of electrical energy will be required?

Mr. Junkersfeld—This must be largely a matter of conjecture. With the very great improvements made in the year just past, it is likely that the increase will be much more rapid—for a time at least—than in the past. I am referring to lights per capita. Mr. Smith stated that at the present time the electrical energy measured as 16 c. p. lamps is something in excess of 3,000,000, and that the population served is 2,000,000, but in the past the ratio has been not nearly so great. What it will be in the future is entirely conjecture.

Mr. J. H. Warder—M.W.S.E.—In connection with the statement that the plants at the Fisk Street and Harrison Street stations are reaching an area of 12 to 15 miles in certain directions to this third zone, I would ask how much further you can carry this electric current economically? Or, if there is to be an urban development beyond that 15 miles, will it not be desirable to install other plants somewhat after the pattern of the Fisk Street station, but further out into that new zone?

Mr. Junkersfeld—That depends entirely on the economy that can be secured from those other plants. If there is difference enough in station economy it will pay to transmit almost any distance. Imagine, for instance, a station where generating cost was, say, three or four times as great as at the Fisk Street station. In that case, even with underground transmission, we might transmit from Fisk Street well into this outer zone, or fourth zone. There are two things that the economical length of transmission depends on: First, difference in levels or annual operating costs, and, second, the fixed charges and losses on the link connecting those two.

Mr. Warder—Would there be any difficulty in installing another plant out on the Des Plaines river, for instance?

Mr. Junkersfeld—Yes, for the reason that we could not get a large plant out there; there is not load enough within reach. In those large plants there is, of course, more economy than in the small ones.

Mr. Roper—Referring to Mr. King's question, the rate of growth of the combined Chicago Edison and Commonwealth companies was approximately at the rate of 10 fold in ten years—1000 per cent. in ten years—while the growth in population is something like 30 per cent., so that the rate of growth in the electrical business has far exceeded the rate of growth in population. This is due in part to the territory covered by the distribution system having increased, and to as large, or possibly a much larger extent by reduction in rates, broadening the field in which the electricity is used. The reduction in rates, of course, cannot continue indefinitely. The rates can be lowered for some years, but each reduction increases the field of usefulness of the current, and until we have arrived at the minimum point in the rates, and have all the territory covered, we cannot look for any constant ratio between the rate of growth in system and rate of growth in population.

Mr. Smith—The development and improvement in the incandescent lamps will have a very important influence upon this growth of demand for electric lighting. For greater economy and higher efficiency in illumination the Tantalum and the Tungsten lamps are now the most prominent to be considered.

EXCURSICN WESTERN SOCIETY OF ENGINEERS TO UNIVERSITY OF ILLINOIS, MAY 11, 1907.

A party of members of the Western Society of Engineers and their friends, numbering nearly one hundred, took advantage of an invitation from the Faculty of the College of Engineering, University of Illinois to visit that institution Saturday, May 11th.

Through the courtesy of the Illinois Central Railroad Company a special rate was secured, and also the use of special cars which were attached to the regular train leaving the city at 10 a. m. and arriving at Champaign about 1 p. m., lunch having been served on the train. The party was immediately conducted to the University Campus, where a tour was made of the Campus and a view of the general layout of the University obtained (the ladies of the party, about ten in number, being first given an automobile tour of the two cities of Champaign and Urbana). The parties were united at the Woman's Building—which is devoted exclusively to the use of the women of the University, and containing in addition to a splendid Gymnasium and swimming tank, a Domestic Science department and other departments devoted particularly to the women students. After this the party was conducted through the Library and then to the group of engineering buildings, consisting of Woodshops, Metal Shops, Electrical Laboratory, Heating Plant, Pumping Plant, Materials Testing Laboratory, Engineering Building, Mechanical Engineering Laboratory, and Hydraulic Laboratory. Here addresses were made by the heads of the various engineering departments, after which various tests and demonstrations were made for the benefit of the visitors.

Prof. Brooks provided a demonstration of a method of synchronizing two alternators without regard to their phase relation; machines were connected in parallel out of step, but by means of the device employed they brought themselves into synchronism without disturbance. This is accomplished by inserting a reactance coil in the circuit of the incoming machines. There was also exhibited a mechanical phase indicator used for demonstrating to students the mechanical meaning of synchronous operation of alternators. Two alternators with their shafts in line were connected mechanically through a differential bevel gear. When the two machines are running at the same speed (in opposite directions), the frame holding the intermediate gear remains stationary. When the machines are synchronously driven by the same alternating current this position is fixed at the four quadrants, as was shown by the tests. The slight difference in phase relation of a machine running as a generator and as a motor was also shown.

In the Materials Testing Laboratory (under the direction of Prof. Talbot) an exhibition was given of the method of testing reinforced concrete beams, columns, rings, etc. A test was made on a concrete column reinforced with bands or hoops. A 48-inch cast iron culvert pipe 8 ft. long, embedded in sand, was tested by subjecting it to external pressure. Experimental work in the Hydraulic Laboratory was also in progress.

At the close of this general inspection tour, the party was divided into groups, thus seeing more in detail those things which interested them most. Part of the visitors were guests at the base ball game between the teams of the University of Illinois and of the University of Chicago; another group took a trip on the Electric Test Car, etc.

Thanks are due Mrs. A. N. Talbot and Mrs. Morgan Brooks for their courtesy in all they did for the entertainment of the ladies of the party.

The train left Champaign for Chicago about 6 p. m., arriving at 9:45. Dinner was served enroute.

The trip was one of the pleasantest we have had for some time, all of the provisions for the comfort and pleasure of the party being well looked after.

P. B. C.

HARMON TRUEMAN—MARCH 22ND, 1907.

Harmon Trueman was born at Truemanville, Nova Scotia, October 28th, 1860.

He attended the public school at Truemanville until seventeen years of age, and during the subsequent four years was a student at Amherst Academy, Amherst, Nova Scotia. The two following years were spent at Dalhousie College, Halifax, and in 1883 he entered McGill University, Montreal, and graduated in April 1886 with the degree of Bachelor of Applied Science.

From July 1886 to March 1889 he acted as Assistant Engineer on the Chicago, Madison & Northern Railroad, and from May 1889 to July 1890 was one of the Assistant Engineers for the St. Louis Merchants Bridge Company.

From July 1890 to August 1892 he served in the Engineering Department of the Illinois Central Railroad. In August of the same year, Mr. Trueman entered the service of the Morden Frog & Crossing Works of Chicago and remained with that firm until his death, being Chief Engineer of the Company for the last ten years.

He was elected a member of the Western Society of Engineers January 19th, 1897 and was also affiliated with the following Masonic bodies: Oriental Lodge No. 33, La Fayette Chapter No. 2, Palestine Council No. 66, of which he was Past T. I. M., and Apollo Commandry No. 1.

He died in Chicago on March 22nd, 1907 of heart failure, and was buried at Amherst, Nova Scotia.

Mr. Trueman was a man of few words and of an exceptionally quiet and reserved nature, but to the few who knew him intimately, he was a staunch and faithful friend. To those in need he was always ready to lend a helping hand.

In his chosen profession he was an acknowledged authority on the multiplicity of detail pertaining to frog and switch work, and will be greatly missed by his friends and business associates.

Arthur C. Smith,
E. N. Layfield.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE REGULAR MEETING, May 1, 1907.

A regular meeting of the Society (No. 604) was held Wednesday evening, May 1st, 1907.

The meeting was called to order at 8.20 p. m. with President Abbott in the Chair, and about 80 members and guests present. The Minutes of the meeting of April 3rd were read and approved.

The Secretary reported from the Board of Direction, that at their meeting of April 30th, the following were duly elected into membership:

Henry J. Sawtell, Chicago	Junior
George F. Gebhardt, Chicago	Active
Ernest Edward Meier, Chicago	Junior
Grant Beebe, Chicago	Active
John C. Gustafson, Chicago	Junior
Wilbur M. Wilson, Ames, Iowa	Active
John C. Thorpe, Urbana, Ill	Active
Edward T. Bent, Chicago	Associate
Knud N. Hojgaard, Chicago	Active
George Bright, Elmhurst, Ill	Junior

The Secretary also reported the following as having applied for membership in the Society:

F. L. Anders, Milwaukee, Wis.	Active
George T. Donoghue, Chicago	Junior
A. Lewis Burridge, Escanaba, Mich	Junior
Roy M. Henderson, Boston, Mass	Active
Linn White, Chicago	Active
Jerre T. Richards, Edison Park, Ill	Active
Ernest D. Kahlert, Chicago	Junior
Roy C. Mitchell, Chicago	Junior
Harold G. Tregillus, Chicago	Junior
William A. Field, Chicago	Active
George W. Wilder, Chicago	Active

Also the following names as having been submitted and whose applications were expected in the immediate future:

A. B. Boyer, Chicago.
J. R. Deardurff, Chicago.
H. J. Ludwig, Evanston.
W. E. H. St. Lawrence, Chicago.
J. B. McIntrye, Chicago.
C. R. Salisbury, Chicago.
W. H. Reinecke, Chicago.

The Secretary also reported that the following persons had been appointed a committee to award the Chanute Medals for the best papers presented before the Society in 1906 in Civil, Mechanical and Electrical Engineering: Mr. B. J. Arnold, Past President, and Messrs. B. E. Grant and C. E. Sargent.

There being no other business to bring before the Society, the Chairman introduced Prof. Robert H. Fernald of St. Louis, who presented his paper on "The Present Status of the Producer-Gas Power Plant in the United States.' This full and elaborate paper had been printed and sent out in advance, so it was not read, but by the aid of numerous lantern slides in illustration, the author gave the substance of the paper in an off-hand talk. The Secretary then read communications from Messrs. T. W. Snow and W. G. Kirchoffer, members of the Society. Discussion followed from President Abbott and Messrs. C. F. Sargent, Lee, Stroud,, Bowen, MacFarland, Lake, and Bement, with a closure from Mr. Fernald

On a motion from Mr. Bement, a vote of thanks was tendered Mr. Fernald for his valuable and interesting paper.

The meeting adjourned about 10.25 p. m.

EXTRA MEETING; May 15, 1907.

An extra meeting of the Society (No. 605) was held Wednesday evening, May 15th, 1907.

The meeting was called to order about 8:15 p. m. with President Abbott in the Chair and about 65 members and guests present.

There was no business to be brought before the meeting, so Mr. W. B. Jackson, M. W. S. E., was introduced, who presented the paper written by his brother Prof. D. C. Jackson of Boston, on "Methods of Electric Lighting of Railway Trains." A limited number of copies of the paper had been printed in advance of the meeting, which were distributed through the audience. Lantern slide illustrations were also used.

The paper was discussed by President Abbott and Messrs. King, Cravath, Freeman and W. B. Jackson.

The meeting adjourned about 10 p. m.

EXTRA MEETING, May 29, 1907.

An extra meeting of the Society (No. 606) was held Wednesday evening, May 29th, 1907.

The meeting was called to order about 8.25 p. m. with Vice-President Layfield in the Chair and about 60 members and guests present.

There was no business to bring before the meeting, so Mr. J. W. Schaub, M. W. S. E., was introduced, who read his paper on "Railway Track in the past and its possible developments in the future," which was illustrated with a number of lantern slides, showing forms of track construction and also the fracture of a number of broken rails.

Discussion followed from Messrs. Field, Finley, Drury, Layfield, Tratman, Camp, C. V. Weston, Bremner, Griswold, Delano, Woodward and Schaub.

A resolution was presented by Mr. Armstrong and carried, that, as this was an important subject and had not been exhausted by the evening's discussion, that written discussion be secured as far as possible, and suggested that the subject be further considered on some subsequent evening.

The meeting adjourned about 10.20 p. m.

REGULAR MEETING, June 5, 1907.

A regular meeting of the Society (No. 607) was held Wednesday evening, June 5th, 1907.

The meeting was called to order by President Abbott about 8.20 p. m. with about 50 members and guests present. The Minutes of the meetings held May 1st, 15th, and 29th, 1907, were read and approved.

The Secretary reported from the Board of Direction, that at their meeting held that day, the following had been elected into membership in the Society:

E. T. Hendee, Chicago	Active
H. Gansslen, Chicago	Active
F. L. Anders, Milwaukee, Wis	Active
George T. Donoghue, Chicago	Junior
A. L. Burridge, Escanaba, Mich	Junior
R. M. Henderson, Boston, Mass	Active
Linn White, Chicago	Active

G. W. Wilder, Chicago	Active
Jerre T. Richards, Chicago	Active
E. D. Kahlert, Chicago	Junior
R. C. Mitchell, Chicago	Junior
H. G. Tregillus, Chicago	Junior
Wm. A. Field, Chicago	Active
A. B. Boyer, Chicago	Active
J. R. Deardurff, Chicago	Active
H. J. Ludwig, Chicago	Active
James B. McIntyre, Gary, Ind	Active
W. H. Reinecke, Richmond, Cal	Junior
Chas. R. Salisbury, Chicago	Active
W. E. H. St. Lawrence, Chicago	Active

Also that applications for membership had been received from:

E. C. Hasselfeldt, Chicago, transfer from Junior to	Active
Henry K. Holsman, Chicago	Active
Llewellyn S. Richards, Chicago	Junior
James C. Hallsted, Chicago	Active
Ralph C. Llewellyn, Chicago	Junior
Irving Parker, Chicago	Active
M. H. Dance, Chicago	Junior
J. Sherman McChesney, Chicago	Junior

The Secretary announced the death, recently, of two members of the Society,—Mr. A. MacArthur, Associate, who died June 1st. and Mr. Wm. D. Hotchkiss, Member, who died June 3rd.

A resolution was offered by Mr. Layfield and duly carried, that President Abbott appoint Committees to prepare memorials of these members to be published in the Journal.

Mr. Trumbull, of the Entertainment Committee, offered a resolution that was duly carried, that a vote of thanks, in the usual form, be transmitted to J. M. White, Dean, and the faculty of the Engineering College, University of Illinois, and to the proper authorities of the Illinois Central R. R., for courtesies extended to the Western Society of Engineers on the occasion of their recent excursion to Champaign and Urbana, Ill.

On a suggestion from the Secretary, as to the usual practice of the Society, a resolution was introduced and duly passed, that the meetings of the Society be discontinued during the months of July and August.

The Secretary announced that the next meeting of the Society would be held Wednesday, June 26th, 1907, when Mr. Isham Randolph, Chief Engineer, Sanitary District of Chicago, would address the meeting on "The Work of the Sanitary District of Chicago already accomplished, and yet contemplated South of the Controlling Works at Lockport."

Mr. C. B. Burdick, M. W. S. E., was then introduced who read his paper on "Methods of Pumping Deep Ground Water," which had been printed in advance. Lantern slide illustrations were used. Discussion followed from Messrs. Abbott, Layfield, Hecht, Spurling, Trumbull, Gansslen, Mead, Hedrick, Boardman and Schaub, with a closure by Mr. Burdick.

The meeting adjourned about 10.20 p. m.

J. H. Warder,
Secretary.

WESTERN SOCIETY OF ENGINEERS

Secretary's Office, Library, Reading Room and Meeting Rooms
1734-41 Monadnock Block, Chicago.

LIST OF OFFICERS FOR 1907

President	W. L. Abbott
First Vice-President	Andrews Allen
Second Vice-President	E. N. Layfield
Third Vice-President	A. N. Talbot
Treasurer	A. Reichmann

TRUSTEES

G. M. Wisner	Term expires January, 1908
John Brunner	Term expires January, 1909
W. C. Armstrong	Term expires January, 1910
R. Modjeski, E. C. Carter, B. J. Arnold	Past Presidents.

The above named officers of the Society and three past presidents, constitute its Board of Direction.

Secretary and Librarian
J. H. WARDER

COMMITTEES

On Finance—Andrews Allen, A. Reichmann, H. N. Elmer.

On Publication—E. N. Layfield, R. F. Schuchardt, L. K. Sherman, C. B. Burdick, O. P. Chamberlain, W. S. Monroe, J. W. Schaub.

On Library—John Brunner, C. H. Cartlidge, P. B. Woodworth.

On Membership—W. C. Armstrong, B. B. Carter, P. Junkersfeld.

On Entertainment—O. J. West, M. K. Trumbull, A. Reichmann.

THE ELECTRICAL SECTION

C. A. S. Howlett, Chairman, D. W. Roper, Vice-Chairman, for 1907.

P. B. Woodworth	1 year
O. E. Osthoff	2 years
K. B. Miller	3 years

Members of Executive Committee.

MEETINGS

Regular Meeting—1st Wednesday evening of each month except January July and August.

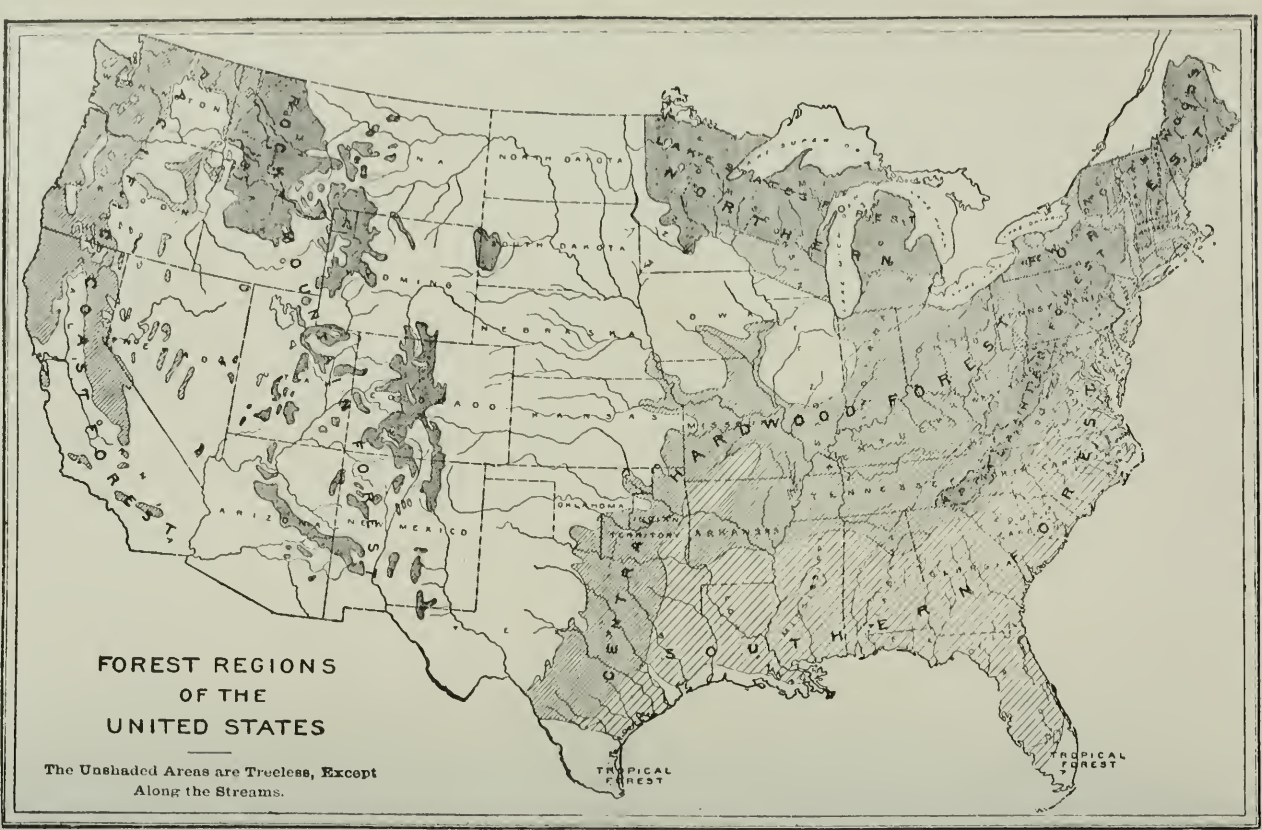
Extra Meeting—3rd Wednesday evening of each month except July and August.

Electrical Section—C. A. S. Howlett, Chairman, generally the 2d Friday of the month, October to May, inclusive.

Board of Direction—The Tuesday preceding the 1st Wednesday of each month.

NOTICE

From the dues of each member, $2.00 is set aside as a subscription to the Journal.



FOREST REGIONS
OF THE
UNITED STATES

The Unshaded Areas are Treeless, **Except**
Along the Streams.

CORRECTION

In the Journal for August 1907, Vol. 12, No. 4, on page 520 line 14, and page 521 line 29, the name should be E. L. Cooley, and not L. E. Cooley as printed.

Journal of the
Western Society of Engineers

VOL. XII. AUGUST, 1907. NO. 4.

SOME PROBLEMS IN WOOD UTILIZATION IN THE UNITED STATES.

By R. S. Kellogg,
Forest Inspector, U. S. Forest Service.

Presented February 20, 1907.

THE SUPPLY.

The annual yield of the forests of the United States reaches huge proportions, and familiar as all are with the use of wood for every purpose and in every industry, it is only when the attempt is made to properly estimate the various items that there is a full realization of the important place the forests fill in the national economy. A rough estimate of the quantity and value of the present yearly output of the forests is given below.

ANNUAL OUTPUT OF FOREST PRODUCTS.

Value, Estimated at Point of Production.

	Quantity	Value
Lumber, Feet, B. M.	35,000,000,000	$500,000,000
Firewood, cords	100,000,000	350,000,000
Shingles and Lath		35,000,000
Hewed cross-ties, Number	70,000,000	30,000,000
Cooperage stock		25,000,000
Turpentine and rosin		20,000,000
Pulpwood, cords	3,000,000	15,000,000
Round mine timbers, cubic feet	170,000,000	7,500,000
Tanbark, cords	1,000,000	5,000,000
Telephone and telegraph poles, number	2,500,000	5,000,000
Maple sugar and sirup		2,500,000
Wood used for veneers, feet, B. M.	200,000,000	2,000,000
Wood used for distillation, cords	700,000	2,000,000
Posts, piles, and other products		3,000,000
		$1,982,000,000

No attempt is made to give more than nearly an approximate statement based upon reports of the Census and the Forest Service, but it is fairly certain that the various items, except that of firewood, are accurate to within ten per cent. No satisfactory data have ever been collected on the annual consumption of wood for fuel. According to an estimate made by the Census in 1880, 146,000,000 cords were used at that time, but in order to be conservative and in the absence of reliable information, the present annual consumption is placed at 100,000,000 cords.

The total quantity of wood which it was necessary to cut in order to obtain the products listed in the table was probably about 20 billion cubic feet. It is probable that the maximum annual output of forest products for the country as a whole has been reached, and that there will soon be a marked decline in quantity, accompanied by a corresponding increase in value. Rapid as has been the increase in population, the increase in lumber consumption has been still more rapid. In round numbers the lumber cut in 1880 was 18 billion feet; in 1890, 27 billion feet; and in 1900, 35 billion feet. The increase in population from 1880 to 1900 was 52 per cent, but the increase in lumber cut was 94 per cent.

The relative rank of the various species in lumber production, based on reports to the Forest Service, is shown graphically herewith. Had reports from all operators been received, the amount credited to yellow pine would have been about 12 billion feet, as this timber is now furnishing practically one-third of the lumbercut of the United States.

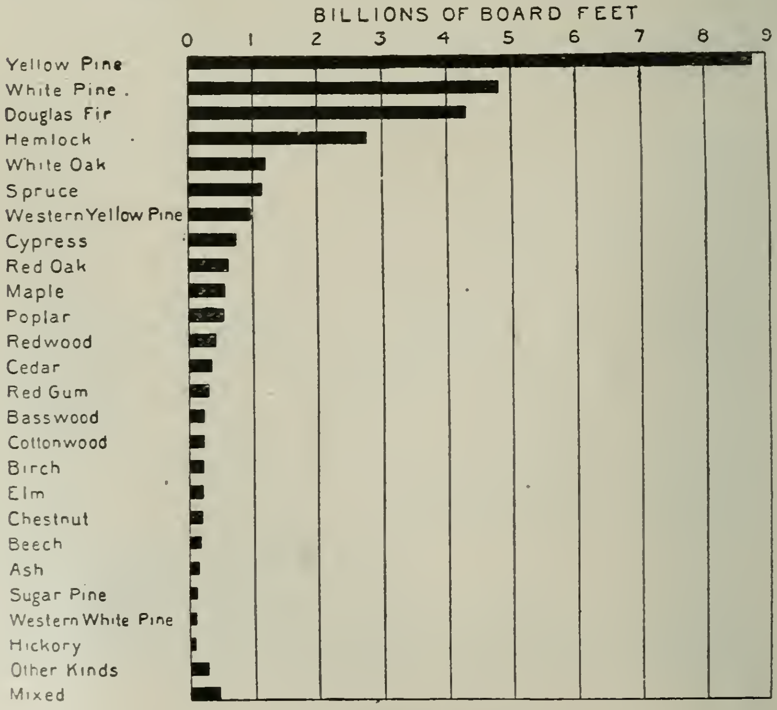


FIG. 1.—Lumber production, by species, 1905.

The steadily advancing prices of leadings kinds of lumber is clearly shown by the following diagram which gives the wholesale prices of white and yellow pine, cypress and hemlock from 1894 to the end of 1905. Since that date there has been a considerable advance in cypress.

So far, the American has been wastefully extravagant in the use of wood. He has wanted the best grades of lumber, even for the building of a chicken coop, or as a prominent lumberman recently remarked—we have insisted that all our cuts be "Porterhouse." However, the time of neck cuts and soup bones is rapidly approaching. Our stumpage fit for the saw is rapidly decreasing. Our estimated forest area is 500 million acres, of which nearly four-fifths is in private hands, and will largely remain so.

The best-managed German forests grow on an average about 50 cubic feet of wood per acre annually. If our forests grew as well, they would barely furnish by annual growth the amount of wood we now use. It is probably safe to say that, under present conditions, the annual growth is not more than one-fifth that of the German forests. We are rapidly using up our forest capital.

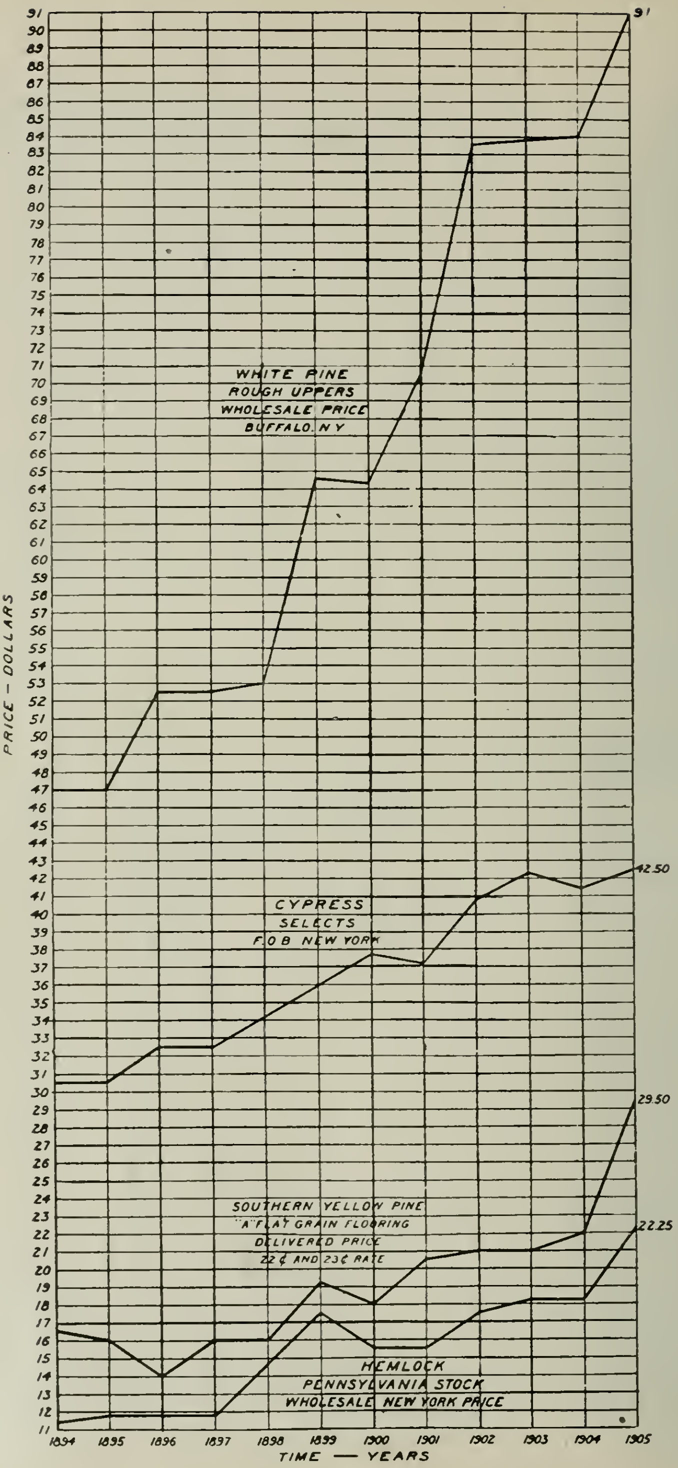
THE PROBLEMS.

Pending the creation of a new wood supply by forest management and planting, we must solve the following problems in order to make our present supply go as far as possible.

Reduction of Waste in Manufacture. According to present practice but little more than 25 per cent of the cubic contents of a tree reaches the consumer in the form of lumber. This would not be important were the other 75 per cent made to serve some useful purpose, but so far this has not been the case. The guiding principle for the future must be that every part of a tree is intrinsically capable of utilization, and that in consequence—

Logging will be done more carefully, stumps will be cut lower, and tops higher. There will be greater care in cutting the tree up, and log lengths will be adapted to the peculiarities of the tree, rather than being arbitrarily fixed. Lops, tops, and stumps will all be used eventually; probably for fuel, excelsior, distillation, or pulp, depending upon the locality and species. Needless to say, thousands of feet of logs will not be used for temporary roads, slides, and skidways, and then left to rot in the woods. Neither will any tree be left to decay simply because it is crooked or of an inferior species. Everything in the forest will be used.

Manufacturing will be more economical. The bandsaw has now largely replaced the circular saw, and it will do so more in the future. This alone means a great saving in saw kerf. Logs will be slabbed more carefully. There is a saving in slabbing a log on four sides instead of on only two sides before cutting it up, but this is not always done. Slabs will be more closely utilized, and even now, the best-managed northern mills find it profitable to run their white pine and hemlock slabs through a horizontal


WHITE PINE
ROUGH UPPERS
WHOLESALE PRICE
BUFFALO, N Y
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CYPRESS
SELECTS
F.O.B NEW YORK
42.50
SOUTHERN YELLOW PINE
"A" FLAT GRAIN FLOORING
DELIVERED PRICE
22¢ AND 23¢ RATE
29.50
HEMLOCK
PENNSYLVANIA STOCK
WHOLESALE NEW YORK PRICE
22.25
PRICE — DOLLARS
11
12
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TIME — YEARS

band re-saw, and so obtain one or two additional narrow boards. There will be less waste at the edger and trimmer. There is little reason for making only even lengths and widths in the stock grades of lumber, aside from large dimension stuff, and it is pure nonsense to cut two feet off from a board because a knot is within six inches of the end. The movement in favor of odd widths and lengths has made notable progress among lumber manufacturers in the last year. We may expect that slabs, edgings, and trimmings will cease going into the burner, and instead be devoted to some useful and profitable purpose. Aside from the usual output of lath and shingles as by-products of lumber manufacture with certain species, we may expect to see some of the present waste converted into small dimension stuff, box boards, crate sticks, and other articles, with always a possibility of conversion into pulp or wood-distillation products. So long as the sawdust feeds the mill furnaces, it may be considered satisfactorily utilized. A comparatively recent departure in lumber manufacture that is rapidly gaining ground is the production of veneer stock. This is a most economical method of cutting up a log, particularly if done by the rotary process, since there is no loss whatever in sawdust, and the cores can be used for crate sticks, box boards, pulp, fuel, or other purposes. Veneering makes the same quantity of material go much further than it would if sawed in the ordinary manner, and the weakening of the demand for quarter-sawed oak lumber is directly chargeable to the increased use of veneer stock. An association has recently been organized and standard grades for veneer stock adopted.

Lumber will be handled more carefully in the yard, and less exposed to injury by the elements. Methods of seasoning, both in the air and in the kiln, will be improved, and loss through warping and checking will be reduced.

Economies in the Use of Wood. We are using annually over 400 feet board measure of lumber per capita, while Europe averages but 60. We can and must learn to use less and use it more judiciously. A great gain is now going on in the use of steel, cement and concrete. A cement block house now costs but little more than a wooden one, and in a few years it will be the cheaper. Rinforced concrete is used for piles, bridges, warehouses, etc. The highest type of modern office buildings are constructed almost entirely of steel, brick, and other artificial material. Cement walks in towns are replacing wooden ones with decided gain in utility. The production of Portland cement in the United States has increased 400 per cent in the last six years.

We can learn to use one fence post, one cross-tie, one mine timber, and one telephone pole where we now use two, and still have the same or a greater amount of service. This is possible through the prolonged life obtained by preservative treatment. The saving in timber along this line will reach into millions yearly.

It is estimated that nearly ten per cent of the annual lumber cut of the United States goes into packing boxes, and in fact 80 per cent of the white pine cut in New England is so used. Yet the life of a packing box is remarkably short, and after serving its initial purpose it is cast into the rubbish heap. Much can be saved along this line.

Mechanical tests upon all the principal woods, to determine their strength, stiffness, and other physical properties, and the effect of knots, checks, and other defects upon commercial sizes, will give the proper basis for grading rules and indicate clearly the kind and quantity of material needed for a given use.

Substitution of Other Woods. Woods which have long been considered inferior or useless will be utilized and in many cases substituted for ones which are getting scarce. The evolution of the wagon box is an excellent example. Once, the standard box board was white pine, then came yellow poplar, then cottonwood, more recently red gum, and to-day the formerly despised tupelo is going into wagon boxes, though surreptitiously,—to-morrow it will hold an honored place. Each of these changes has come about as a result of the decreasing supply and increasing price of the wood formerly used.

Similarly, axles are being made of maple instead of hickory, and implement poles of long leaf pine instead of oak.

Though it does not seem at present possible to get something else equally as satisfactory as hickory for buggy parts, elm for slack barrel staves and hoops, and white oak for tight cooperage, there is a great field of possible substitution, since so little is really known of the essential properties of most American woods.

These remarks simply indicate a few of the big problems which are waiting to be solved. It is a time of rapid changes and readjustments to new economic conditions, and the users of the forests must be prepared to face them. Happily, there is every indication that eventually these conditions will be successfully met. The potential forest area of the United States is sufficient, if rightly managed, to produce all the wood we really need. The lumberman, if not just now, can soon afford to handle his lands according to forestry principles, and the national forests, while at present a relatively small factor in the annual output, will rapidly increase in importance.

It is the duty and privilege of the forester on the one hand to demonstrate how these products may be made as abundant and of as high a grade as possible, and on the other hand to indicate how they may be utilized most economically and advantageously. Surely, this is an object worth striving for.

DISCUSSION.

President Abbott: From the table shown on the screen I judge there is about five times as much wood used for firewood as for all other purposes combined.

Mr. Kellogg: A cord of wood is usually supposed to be equiva-

LUMBER CUT OF UNITED STATES—1880-1906—M. F. T.

	Reported by Census of				Estimated Total Cut	
State.	1880	1890	1900	1905	1880-1906	Per Ct.
Alabama	251,851	586,143	1,096,539	1,243,988	19,625,000	2.8
Arkansas	172,503	526,091	1,595,933	1,680,536	23,932,000	3.4
California	304,795	515,823	734,232	1,077,499	15,789,000	2.2
Colorado	63,792	79,906	133,746	141,914	2,614,000	.4
Connecticut	64,427	48,277	107,594	69,376	1,874,000	.3
Florida	247,627	411,436	788,905	812,693	14,802,000	2.0
Georgia	451,788	572,970	1,308,610	1,135,910	21,865,000	3.1
Idaho	18,204	27,800	65,331	211,447	1,526,000	.2
Illinois	334,244	218,938	381,584	211,545	7,548,000	1.1
Indiana	915,943	707,115	977,878	563,853	21,165,000	3.0
Iowa	412,578	568,816	351,769	281,521	11,410,000	1.6
Kentucky	305,684	420,820	765,343	586,371	13,618,000	1.9
Louisiana	133,472	303,591	1,113,423	2,459,327	19,989,000	2.8
Maine	566,656	564,243	756,515	863,860	17,119,000	2.4
Maryland	123,336	81,078	183,393	166,469	3,394,000	.5
Massachusetts	205,244	208,655	342,058	262,467	6,637,000	.9
Michigan	4,172,572	4,245,717	3,012,057	2,006,670	93,436,000	13.2
Minnesota	563,974	1,079,403	2,341,619	1,942,248	38,174,000	5.4
Mississippi	168,747	452,797	1,202,334	1,727,391	20,173,000	2.9
Missouri	399,744	395,755	715,968	553,940	13,346,000	1.9
Montana	21,420	89,511	255,685	236,430	3,757,000	.5
New Hampshire	292,267	266,890	562,258	491,591	10,103,000	1.4
New Jersey	109,679	32,285	72,660	44,058	1,585,000	.2
New York	1,184,220	909,990	874,754	581,976	23,765,000	3.4
North Carolina	241,822	509,436	1,278,399	1,318,411	20,486,000	2.9
Ohio	910,832	541,076	957,239	420,905	18,886,000	2.7
Oregon	177,171	444,565	734,181	987,107	14,166,000	2.0
Pennsylvania	1,733,844	2,113,267	2,321,284	1,738,972	53,598,000	7.6
South Carolina	185,772	197,940	466,109	609,769	8,466,000	1.2
Tennessee	302,673	450,097	939,463	775,885	15,858,000	2.3
Texas	328,968	839,724	1,230,904	1,406,473	24,109,000	3.4
Vermont	322,942	370,155	365,869	337,238	9,255,000	1.3
Virginia	315,939	409,804	956,169	949,797	16,176,000	2.3
Washington	160,176	1,061,560	1,428,205	2,485,628	30,299,000	4.3
West Virginia	180,112	299,709	773,583	855,889	12,654,000	1.8
Wisconsin	1,542,021	2,817,200	3,361,943	2,623,157	70,647,000	10.0
All others	200,317	126,270	226,977	264,854	4,875,000	.7
Total	18,087,356	23,494,853	34,780,513	34,127,165	706,712,000	100.00

lent to 500 or 600 ft. B. M. of lumber, and to contain 70 to 100 solid cu. ft. of material. This would indicate that there is nearly twice as much wood used for fuel as for lumber—if the estimates are correct.

President Abbott: The value of the output of firewood—$350,000,000—is very close, then, to the mine value of the coal output of the United States. It occurred to me that possibly you might be in error in assuming that the amount of firewood has increased somewhat proportionately.

The Forest Service is advising land owners in the matter of tree planting, I am told. At what value of land does it find tree planting profitable?

Mr. Kellogg: That depends entirely on the place and upon the species to be used. There are cases here in Illinois where I feel perfectly sure that tree planting for small material would pay good interest on land worth $100.00 an acre. On the other hand, to go out and plant some of the trees that require a long time to grow, to be finally used for lumber and not for other purposes, would require much less valuable land.

Up in New England, where white pine is planted for box boards, it is considered a paying investment to plant on land that is worth $5.00 an acre.

President Abbott: Is white pine the most valuable crop to raise for general market (so considered) or are there some other species that are preferable?

Mr. Kellogg: In New England it would be the most profitable to plant white pine, and it may be best, on some of the lands that are fit for little else in the lake states, to plant white pine.

President Abbott: But on land at a value above $5.00 an acre it would not be considered sufficiently profitable to pay interest on the investment, would it?

Mr. Kellogg: I am not sure that $5.00 per acre is the outside figure. I am not sure that it will not be a somewhat higher valuation than that. The state of Connecticut has authorized the purchase of land through Connecticut for the planting of trees, at not to exceed $4.00 an acre.

Mr. J. H. Warder, M.W.S.E. Are the sand-dunes of northern Indiana and in the neighborhood of Chicago suitable for forest planting?

Mr. Kellogg: Yes, I think so. But there would be difficulty on account of the blowing away of the sand. You might have to put up artificial barriers to stop the shifting of the sand. As far as the sand itself is concerned, the forest would grow all right. France has done pretty well in the reclamation of sand-dune land. They put in artificial barriers for protection.

Mr. Warder: Are they in the nature of low growing surface plants?

Mr. Kellogg: Yes, often. France has built up some very profitable forests on that character of land recently. The Forest Service is planting some such land in Nebraska, but it is generally grassed over and there is not much drifting.

President Abbott: I understand from your remarks that it takes forty years to raise pine trees to a marketable size. Am I correct in this?

Mr. Kellogg: Yes, roughly speaking, to get them the proper size to be used in box factories.

President Abbott: There are some more valuable woods that would grow to a larger size in that same time, are there not?—walnut, for instance.

Mr. Kellogg: Walnut will grow to a large size, but will not reach its valuable stage in that time. Walnut is a tree that forms heart-wood fairly late in life; the heart-wood is not much developed until the trees get past 50 years of age. That is one of the unprofitable features of walnut, it forms heart-wood so late in life.

President Abbott: What other trees are recommended for planting?

Mr. Kellogg: It depends entirely on the region. In Illinois I would recommend hardy catalpa, osage orange or black locust.

President Abbott: That kind of tree grows in, say, fifteen years or thereabouts, doesn't it?

Mr. Kellogg: You could get a good many posts in fifteen years, and at the end of twenty years you could figure on cutting your entire crop and starting over again.

Mr. R. G. Lawry, M.W.S.E.: What are some of the methods used by the Forestry Department to educate the people along forestry lines?

Mr. Kellogg: It distributes publications on the subject as widely as possible. Then the Forest Service sends men to attend meetings in different parts of the country, wherever it can do so. It does not turn down any more requests than it can possibly avoid. Its publications are also widely reproduced in the trade journals. There are press bulletins, a column in length, on general subjects, which go into the newspapers. Then there are what is called trade bulletins, which go to the technical journals. If we get out a lumber bulletin, we send that to lumber journals only, etc.

Mr. Lawry: Does the Government contemplate any legal way of taking care of private forests?

Mr. Kellogg: No; that is the German way, and it might be a good thing for the United States, but we could not put such a plan into effect.

Mr. H. M. Morse, M.W.S.E.: What means are the Government taking to extend the forest reserves?

Mr. Kellogg: There are many. The Government is increasing the forest reserves, and 130,000,000 acres of such have been created since 1892.

President Abbott: Does the Government go to the extent of planting trees?

Mr. Kellogg: Yes, it is beginning to plant trees on its reserves.

President Abbott: How is it done—by seeding?

Mr. Kellogg: Yes; the seed is collected in the forest, and planted in nurseries, and then after the trees are two or three years old they are set out. In general the raising of trees is done by seeding.

President Abbott: What does it cost per acre for planting?

Mr. Kellogg: That depends to some extent on the cost of seedlings. Where planting can take place the most easily, trees can actually be set for not to exceed $3.00 per thousand, and you may set 1,200 to 1,800 on an acre of land.

President Abbott: Then it might cost $5.00 an acre to plant?

Mr. Kellogg: Yes, possibly $6.00 or $8.00 per acre, but it will cost less after we get the matter thoroughly well worked out and under favorable situations.

President Abbott: What kind of trees are planted?

Mr. Kellogg: Mostly pine.

President Abbott: Will forests grow in climates that are too arid for farming?

Mr. Kellogg: To some extent, but not very well. We do have some very fair western yellow pine that grows in regions where the annual rainfall is about 20 in. and sometimes down to 16 in., but most of the western forests are on the mountains, and between the mountains it is arid.

Mr. Darst, M.W.S.E.: Are you taking care of the red-wood trees?

Mr. Kellogg: There are a few of the big trees in the forest reserves. The saving of the red-wood would once have been a comparatively easy matter, but the red-wood holdings are now all in private hands and the cut is increasing. There is a large amount of standing red-wood timber, however, and red-wood lumber will be on the market for sometime.

President Abbott: Are these forest reserves some that have been denuded of trees, or are they some that have never had trees on them?

Mr. Kellogg: Some of them have had trees and were created for planting purposes; then again others have considerable areas that were cut over before they were reserved. Most of the reserves, however, are forested.

President Abbott: Is any effort being made to leave trees for seeding?

Mr. Kellogg: Yes. No trees are cut on the forest reserves that are not designated as being fit to cut. The Forest Service has made working plans in some cases. It is a feasible proposition in many situations.

Mr. Darst: The old tree claims are not given out any more, are they?

Mr. Kellogg: No, the law was repealed in 1892.

This subject has been further elaborated since the date of its presentation to the Society, and has been printed as *Forest Service—Circular 97*—THE TIMBER SUPPLY OF THE UNITED STATES. This can be had on application to the authorities at Washington, D. C.: The United States Department of Agriculture, Forest Service.—ED.

HOW TO PREVENT FAILURE IN CONCRETE CONSTRUCTION.

Dr. W. Michaelis, Jr., m. w. s. e.

Presented March 6, 1907.

In the following I wish to present my views on the merits and limitations of cement and concrete and on the causes of failure in concrete construction, and will suggest means for the prevention of such failures. In doing so I will take my stand between the manufacturer and the user of cement, that is to say, I will discuss this subject as consulting engineer who is familiar with both the details of the manufacture of cement and its chemical and physical properties and with the use of cement as building material. I will not side with either the manufacturer or the consumer, but will endeavor to point out what can be expected of cement and what not. The manufacturer frequently greatly exaggerates the advantages of cement. According to him there is hardly anything in the building line that cannot be made of concrete. On the other hand, the engineer and architect, who are frequently not acquainted with the intrinsic value of cement with its physical and chemical properties, frequently make unreasonable demands and misinterpret the failures in concrete construction that unfortunately so often occur. To my mind, the best and surest way to advertise cement, to recommend concrete construction, and to give the engineer and architect confidence in this modern building material, would be to minimize the danger of failure as far as possible by proper building ordinances, which would compel the contractor to handle the material in a prescribed way and to make proper tests.

Concrete is a wonderful material in the hands of a skillful contractor and has many advantages over other building materials; but it is the unsafest of all materials, if it is handled by an inexperienced, careless and dishonest builder.

I shall dwell only in a general way on the wide possibilities of concrete construction and point out a few cases where concrete cannot be used:

Concrete offers great resistance to compression, but only comparatively slight resistance to tension. Therefore we can make use of plain concrete in cases in which it is subjected chiefly to compressive stresses, for instance, in foundation work, walls, piers and columns. In all other cases, where it has to resist tensile stresses, as in girders, beams and floors, we have to reinforce it with steel of high tensile strength. The union of concrete and steel thus obtained can be made to fulfill any requirements as to compressive and tensile strength, according to the greater or lesser amount of concrete or steel used in each special case. In some cases the compressive strength of the steel is made use of at the same time as its tensile strength, namely, when the dimensions of the concrete work have to be reduced to a minimum, as often in columns and piers.

Piers and columns are often reinforced by plain round rods, placed near the circumference and connected by wire or ties. This kind of reinforcement is liable to be the cause of disaster, if an insufficient percentage of reinforcement is used, either in the designing or by negligence of the contractor, who may omit some of the bars. Columns insufficiently reinforced by bars, fail suddenly by pushing the steel rods apart. A safer way of reinforcing columns is to make use of spiral reinforcement. Such columns fail by bending and give ample warning before failure. There is a creaking noise of the compressed concrete and scaling off of the concrete on the surface of the columns; then the column is slowly bent out of shape before it collapses. This kind of reinforcement, therefore, should be used exclusively for columns which have to sustain heavy loads.

Girders and beams are reinforced by tension rods which are imbedded in those parts of the concrete which are subjected to tensile stresses. The reinforcement consists either of several single bars, horizontal and partly turned up, which are held in place by stirrups or U-shaped iron, or by bars which present a rigid combination of bar and stirrups. This latter method is much safer, because it makes it impossible for the contractor to omit some of the stirrups; moreover, all parts must necessarily maintain their relative positions with respect to one another and chances of defective work from faulty placing of steel are largely avoided.

Floors and ceilings are likewise reinforced by steel rods imbedded in the lower part of the layer of concrete to take up the tensile stresses.

In all cases the mechanical laws that govern this type of construction are the same as in steel construction; therefore the methods of calculation are the same. The only difference is that in steel construction we have to deal with but one kind of material, while in reinforced concrete construction we have to figure with two kinds of materials of entirely different physical properties. Of these we let the concrete as a rule take care of itself, whenever compressive strength is required, and call upon the steel reinforcement only where tensile stresses occur.

Modern methods of reinforced concrete construction frequently make building possible on grounds on which other material can not be used. For instance, in places where wooden piles would rot, reinforced concrete piles are driven, and on sites where the soil cannot be depended upon, as on river banks and sea shores, a solid foundation is obtained by a reinforced concrete raft, which transmits the load over the whole available area and which, owing to its rigidity, does not give way, even if there should be a settlement of the ground at any particular point.

The monolithic connection of foundations, columns, girders, beams and floors, on account of its unequalled rigidity, is a decided advantage over the freely supported girders and beams of wood and steel construction. This is particularly true in places where earthquakes have to be considered.

However, concrete cannot be used everywhere, as there are some limitations to its use. In some parts of the country cement is too expensive, or good sand or crushed stone cannot be obtained. In others the high cost of lumber for forms excludes concrete construction. This latter point becomes more and more serious from year to year with the growing advance in the price of lumber. The cost of the wooden false-work and the labor cost of installing and removing it amounts sometimes to 50 per cent of the cost of the structure. In such cases another method has been adopted, which does away with a large part of the lumber, namely, the casting on the ground of columns, beams, girders and floor slabs, which are afterwards hoisted and erected as with structural steel work. This saves the centers and supports and reduces the cost of erection but at the same time it sacrifices the main advantage of concrete structures, namely, their monolithic character.

The erection of a concrete building, as a rule, takes considerably more time than that of a steel structure, at least if it is done with care and if all parts are given plenty of time to set before removing the forms. This is a serious item in the cost of the building, in case of a large office building or hotel, because every month which it takes longer to erect the structure means a considerable loss in rental from the building. Some cases, however, have been pointed out where the erection of a concrete office building has not required more time than that of a steel skeleton building. But such practice is extremely dangerous and should not be approved, unless the contractor can demonstrate by continuous tests that the concrete work is strong enough to sustain the superimposed load and that he is justified in removing the forms.

The principles governing modern reinforced concrete construction are thoroughly understood by comparatively few. This explains the divergence of opinion on many points pertaining to this branch of the building industry.

While some engineers are careful to specify concrete of ample strength, others blame such "over-cautious" builders for making use of an excessive factor of safety. The aim is, of course, to reduce the cost of concrete as far as possible in order to give it the widest application possible. But if engineers fail in their efforts to prove that for a given case, concrete work would be less expensive than steel construction, they frequently blame the cement for it, and we can hear all kinds of theories advanced. They will say, for instance, that cement is not sufficiently uniform at present, and they claim that if cement could be so manufactured as to give as uniform tests as does steel, it would be possible for the engineer to reduce the larger factor of safety now demanded for concrete over that required for steel. Such a statement is entirely without foundation.

Cement is manufactured of sufficient uniformity nowadays, at least by plants which can depend upon uniform raw materials. Cement can be manufactured as uniform in quality as steel. But in comparing the cost of steel and concrete construction and their respective safety factors, we are not allowed to compare steel with cement, but steel with concrete. Steel is a well-defined chemical compound rolled into the desired shape. Concrete, on the other hand, is the sum of a number of factors, namely, of cement (a chemical compound equally well-defined as steel and ground to the desired fineness), of crushed stone, of sand, of water, of workmanship and of a great deal of care, a combination of which cement is a comparatively small part. The calculation of a steel girder and that of a reinforced concrete girder or beam can never be based on equal safety factors, no matter how much the properties of cement may be improved in the future.

Moreover, cement will not be improved in the future; we have arrived at the limit of its good qualities. In making this statement, I refer to Portland cement, of which every builder in this country thinks, whenever the general term "cement" is used. Why can Portland cement not be improved? In order to be able to answer this question, I must remind you that Portland cement is a product obtained by calcination of an intimate mixture of finely pulverized limestone and clay or shale, and that it consists of calcium silicates and calcium aluminates. Clay and limestone may be mixed in all possible proportions, but the result from a chemical standpoint will never be anything better than our present commerical Portland cement. Then, if the chemical composition of Portland cement cannot be improved, cannot its physical properties be altered, can it not be ground more finely? Yes, this latter can be done, indeed, but it would not be of any practical value.

Recent investigations have proven that of our commercial Portland cement only from 30% to 40% possess cementing properties at all; the remaining 60% to 70% represent inert material. Until a short time ago, you could read in cement literature that the cement remaining on a 200-mesh sieve is too coarse, that is to say, has no hydraulic properties, and that everything that passes the 200-mesh sieve represents the active part of the commercial cement. Today the 200-mesh sieve exists only for the manufacturer in order to enable him to grind his clinker always to a certain fineness required by the specifications. The experimenter, however, can no longer make use of so coarse a screen as a 200-mesh sieve. He divides the cement into that part which remains on an 800-mesh sieve, which is inert (about 60—70%), and that which passes the 800-mesh sieve (30—40%), which is cement proper. Of course, an 800-mesh sieve does not exist. It would have meshes 1/1600 (one sixteen hundredth) of an inch wide and would consist of wire gauze of the same thickness. In order to obtain this fineness, the imaginary sieve is replaced by a process of decantation or elutriation in a current of alcohol of a certain velocity which separates the fine from the coarse and leaves the grains that measure more than 1/1600 (one sixteen hundredth) of an inch under the microscope.

If the manufacturer would grind his Portland cement to this extreme fineness or even only to a fineness between the 800-mesh sieve and that of the commerical cement of today, say to 70% passing an 800-mesh sieve, the resulting product would be so quick-setting a cement that nobody would be able to use it in practice. A neat or a sand mortar briquette may be made of it possessing a strength several times higher than the strength obtained from Portland cement of the present fineness, but this is only under the assumption that the mortar begauged with the water less than a minute. If the gauging should continue for several minutes, no higher strength than for ordinary cement can be obtained. This is due to the quick-setting qualities of the calcium aluminates in the Portland cement. No addition, however great, of any retarding element, can prevent this. So finely ground a Portland cement, therefore, could not be used in actual practice, where under the best conditions a quarter of an hour is required from the time of mixing the concrete until it is tamped into the forms or moulds. I have frequently made such experiments with cement of extreme fineness separated from the coarser particles by an air-current for instance, with cement that had been collected on the top of a 30-foot ventilating tube over grinding machinery, and from these experiments I know that such Portland cement will never fulfill the demands of engineers and architects who are eargerly looking for a cement of higher crushing strength than our present Portland cement. Architects rightly wish both for economic and mechanical reasons, to disuse reinforcement in concrete columns. As long as they make use of Portland cement for their concrete, they will have to design columns of enormous proportions, if they want to omit reinforcing bars or spiral reinforcement. Therefore the desire for a much better grade of cement, which according to a recent utterance of a well-known engineer, "would receive an enthusiastic reception by all engineers." Fortunately such a cement exists.

The cement to which I refer is "Iron-ore Cement" which has been manufactured for several years in Germany, and which I hope will soon be manufactured in the United States also. This cement is made of limestone and iron-ore instead of using limestone and clay as in the manufacture of Portland cement. It was originally manufactured with the sole intention of replacing Portland cement for sea-water construction, because Portland cement is rapidly destroyed by the magnesia sulphate contained in the sea-water, while iron-ore cement is not acted upon by even the most concentrated solution of sulphates. This iron-ore cement, if ground to the fineness of commercial Portland cement, is very slow setting, because of its chemical composition, which differs from that of Portland cement in-as-much as the aluminates of the Portland cement are replaced by iron compounds, by calcium ferrites. The aluminates of the Portland cement, as mentioned above, are the cause of its quicksetting properties. The calcium ferrites of the iron-ore cement, however, hydrate slowly, so that this cement has a comparatively low strength after a day or a week. But its strength steadily increases from month to month and year to year, soon reaches that of Portland cement and in time far exceeds its maximum strength, so that a barrel of iron-ore cement goes much farther than a barrel of Portland cement even under ordinary conditions; that is to say, if both are ground to the same fineness as at present. Now let us grind iron-ore cement to extreme fineness, which can easily be done by air-separation; it will finally become as quicksetting as commercial Portland cement is now, it will contain perhaps 70-80% of active material as compared with the 30-40% of Portland cement of the same setting properties. A barrel of such finely pulverized iron-ore cement will replace three barrels of Portland cement and will enable the architect either to use leaner mortars or to considerably reduce the dimensions of columns and beams. As mentioned before, this cannot be done with Portland cement. Moreover, a better grade of cement could be shipped farther, as the consumer would obtain in one barrel of cement the same amount of cementing material as is contained in three barrels now.

In the foregoing I have pointed out some of the advantages and disadvantages of concrete work and of various kinds of reinforcing systems and have discussed what can reasonably be expected of Portland cement. I have also called attention to the demands of engineers and architects for a higher grade cement, which demand is likely to be met in the future. I will now discuss, how, with materials at present available the frequent deplorable accidents can be prevented.

As said before, cement is manufactured so uniformly and is generally tested so thoroughly at the plants before being shipped, that only in comparatively few cases is the cement to blame for the failure of concrete work. In most cases the builder has himself to blame for the collapse of a structure. In work of minor importance, for instance in sidewalk work or in the manufacture of concrete blocks, failures can be noticed every day. Where cement is thus used on a comparatively small scale, cases happen, where failure is due to poor cement, as usually only the consumer of large quantities of cement makes tests of his own and can find out in advance, whether or not he has received a reliable product from the manufacturer. Thus it sometimes really happens that a small consumer receives a carload of cement, which has not the proper setting time, and which he kills in working it. Cement companies who have not uniform raw materials or whose materials are too high in alumina often have trouble in regulating the setting time and they supply the consumer now and then with a cement with which he is unable to work. To this group of manufacturers likewise belong those companies who do not pay enough attention to thorough vitrification of the clinker. If the clinker is merely burnt to a point of beginning vitrification, if a friable clinker is obtained which just passes the specifications after a little curing and doctoring, it happens that this cement disintegrates after having been shipped, changes its setting properties and becomes a quick setting cement, while it may have had a medium setting time when it had been tested at the works. In using the term "disintegrate" in this case I do not refer to the dusting on cooling of overburnt clinker or clinker too high in silica, but to the breaking up into smaller fragments which every clinker shows on aerating, unless it is burnt to a dense, vitrified piece of rock. Such a cement is ground at the factory like all others to the fineness of a commercial cement.—About 30 or 40% of it would pass the 800-mesh sieve, when it is tested before leaving the plant. But it continues to disintegrate after being packed in sacks or paper bags; the moisture of the atmosphere breaks up every little particle into smaller fragments and in time a much higher percentage of the extremely fine powder is found than when shipped and the result is that the cement which may have set in two or three hours when tested at the plant, now begins to set instantaneously. There are very few consumers of cement or even chemists and superintendents of cement plants who are able to detect this. If you give them a cement which begins to set in 5 or 10 minutes, they will find it out, but if they get hold of a cement which sets immediately, they frequently do not discover the fact, and afterwards wonder at the poor results obtained with it. Some six years ago commercial cements of even the largest plants of the Lehigh Valley could frequently be found to set instantaneously, although the men at the works were not conscious of the fact. But nowadays such cases become more and more rare, and we may safely say, that in nine out of ten cases the consumer of cement is to blame, if we consider only sidewalk work or the manufacture of concrete blocks. In these branches of the business we see any number of incompetent people engaged, who handle a few dozen barrels of cement a day, who cannot be expected to make elaborate tests of cement and who would not be able to make them correctly, even if they wanted to. In all other cases, where work of larger proportions is involved, namely in the construction of residences, factories, office buildings and hotels, the manufacturer of cement can never be blamed for failure during the course of construction, because it is the business of the builder to test his cement thoroughly before using it. The building ordinances of all states should compel builders to submit the cement to thorough tests before using it, no matter how well-known a brand of cement they may have bought. Such a law would obviate the few possible cases, where cement might otherwise be blamed for destructive failures. After this has been settled we would have to consider how the many failures can be prevented where the builder himself is at fault.

In order to understand the situation we have to ask at first: In what respect do masonry and steel construction and concrete construction differ? The old-fashioned way is to erect structures of material of known strength as by piling brick of a certain compressive strength, one on the top of another, to construct walls and piers and then to connect the piers by means of wooden or steel girders and beams of known strength. In steel structures the masonry piers are replaced by steel columns to which are securely riveted steel girders and beams which carry the floors. In this class of construction comparatively few failures can occur, if the designs have passed through the hands of a careful board of building examiners and if the material, brick, steel and wood, conform to the specifications. The members may be jointed and riveted together in a negligent way; but this can easily be detected by building inspectors and careless work can be replaced. In concrete construction, on the other hand, the strength of none of the members of which the structure is composed is known in advance. The designs may have passed through the hands of competent and careful examiners, who may have scrutinized every detail of the construction and found it to conform to other previous designs which have proved a success, and yet the erection of the building may result in complete failure and great loss of life. No other building material is apt to result in destruction of equal magnitude, if handled carelessly. All that the builder of concrete work knows, when starting to carry out the design before him, is the strength of the cement and that of the reinforcing bars, if he has gone at all to the trouble of having both examined, one for crushing stress and the other for tensile strength. Then he proceeds to erect the forms and supports, mixes crushed stone, sand and cement in certain proportions and tamps the concrete into the moulds. After a certain time he comes to the conclusion that the concrete has had time enough o set, that he needs the centering at some other part of the building, and orders his men to remove the forms; and in many cases it is more or less of a pleasant surprise to him, if the building does not collapse on striking the forms. Experienced contractors who can depend upon a well trained gang of workmen and have reliable men to superintend the work, will be able to tell quite well how much of a load a column or beam will stand after a certain time, but with most contractors it is only guesswork, and such a state of affairs should not be tolerated.

Before a railway company is allowed to entrust the life of passengers to railroad cars, have they not to test every part of the structural material that goes into the design of a car and do they not break one wheel arbitrarily selected out of a certain number before they draw definite conclusions as to the safety of the materials? And in masonry and steel construction are the crushing strength of brick and the tensile strength of steel not carefully determined before they are used for construction work? But have you ever heard that builders of concrete work have carefully ascertained the actual strength of a beam or girder before removing the centers? I have not. They may occasionally make a few tests on the tensile strength of the cement, which they have bought, but hardly ever on its compressive strength, or they may even go as far as making a few concrete cubes from the materials which they use later on during the construction; but all these tests do not permit them to draw any definite conclusions as to the actual strength of the concrete which goes or has gone into foundation work, walls, columns, girders, beams and floor slabs. I do not wish to be misunderstood and therefore will immediately mention the numerous tests of girders, beams and floors which have often been made in order to demonstrate the merits of thorough reinforced concrete work and which have proven what excellent work can be done by experienced contractors. But on the other hand we have before us such work as that which results in failures like the collapse of the Bixby Hotel at Long Beach, California, and that of the factory building of the Eastman Kodak Co., at Rochester, N. Y. These failures have proved that the concrete, which can be made of the materials on the premises and which probably has been made in the form of a few concrete cubes before starting operations, and the concrete that is actually made during the course of construction are in many cases two entirely different things. Therefore my insistence upon continuous tests of the concrete which goes into girders, beams and so forth. As I described to you before, cement is but a comparatively small factor in the manufacture of concrete and in addition to sand, gravel, crushed stone and water a number of other factors have to be taken into consideration, for instance, workmanship. How true this statement is, you may see from the causes of the collapse of the two structures just referred to.

From the information received on the subject it is evident, that in the first place both structures were designed too weak, the architects in both cases should not have been allowed to erect the structures. In both of these structures the columns seem to have been the weakest part of the construction. In one case at the Bixby Hotel, the columns were of apparently ample proportions, namely, 21, 20, 16, 12, 12 and 10 in. sq. from basement to fifth story. But the reinforcements in these columns consisted only of four ½ in. rods, which were tied together by wire at intervals of about 16 in. In the case of the Eastman Kodak Company's building the drawings, called for columns 18 in. sq. up to the main floor and 12 in. sq. above it, and the reinforcement was supposed to consist of four ¾-in. rods and four Kahn-bars in the lower part of the columns and of four Kahn-bars in the upper stories. If the columns had been built according to these specifications, they would have been too weak for the heavy load which they were expected to sustain, or at least the design would be called defective, because it did not make use of a proper safety factor, but the contractor did not even make the lower part of the columns 18 in. wide. He made the columns 12 in. wide throughout and, moreover, omitted in some of the columns the reinforcing rods and reinforced them only by four Kahn-bars all the way through.

The four ½-in. rods at the corners of the columns of the Bixby

Hotel which had a sectional area of 400 and 250 sq. in. in the lower part of the building you can imagine cannot have been of much consequence. The Kahn-bars in the columns of the other structure have not been of much more use. They represent plain bars with stirrups fastened to them and are, from a theoretical standpoint, better than rods of course, but have this disadvantage that their prongs or stirrups, which point up and down in the columns and are bent to an angle of 45 deg. to the bar proper, are in the way in tamping the concrete into the forms. For the columns in question which had to carry a very heavy load spiral reinforcement would have been the proper thing, and I hope the time will not be far, when reinforced concrete construction will be standardized to some degree and the building ordinances will only admit such kinds of reinforcement which offer plenty of security, for instance exclusively spiral reinforcement for all columns in the basement and lower stories of high structures, and Kahn-bars or similar reinforcement for girders and beams, where they are in their proper place.

But faulty design has not been the sole cause of the terrible accidents which accompanied the collapse of these two buildings. Only parts of the buildings came down; most of the columns were just strong enough to carry the superimposed load. To defective design was added careless or even dishonest workmanship.

The concrete work in many parts of the building of the Eastman Kodak Co. had been done with so little care that at a number of columns and girders the reinforcing bars showed at the surface and the bars of the girders were frequently not surrounded by concrete, showing that no care had been taken in tamping the concrete under the bars. Some girders were deformed by carelessness in bracing the forms; and porous concrete and long internal cavities, several inches deep, could be detected everywhere in columns and girders. Moreover, at many places the concrete plainly showed that it had been made with dirty sand, and leaves, saw-dust, shavings and even blocks of wood could be discovered in it. Although the same gross negligence in making the concrete could not be stated after the Bixby Hotel failure, it is apparent that weak concrete work in some of the columns must have been the cause of the failure, thus giving a start to the collapse of the entire middle section of the building. Hence the columns of the Kodak building were slightly better in design and the collapse was mainly due to careless workmanship, and to the too early removal of the forms, while in the case of the Bixby Hotel, faulty design was the primary cause and weak concrete at a number of places and the too early removal of the wooden supports was the ultimate cause of the disaster.

Those of you who know how little attention is frequently paid to thorough mixing of concrete and with what haste the work is done, will understand that poor concrete is a very common cause of failure. The work is often done automatically; crushed stone, gravel, sand and cement are fed into the mixer in the desired proportions from individual hoppers. Unless the supervision is very severe in such a case, it may happen that one of the hoppers chokes and the material flows less freely, thus entirely changing the proportions of the concrete. Such unintentional mistakes amply suffice to bring about disaster; but if to these intentional carelessness is added and the concrete is weakened wilfully, hardly anything but failure can be the result.

One or the other of the above mentioned weaknesses in the design or in the concrete work may be present in any concrete construction, and the contractor can never be absolutely sure that his building will not collapse on removing the woodwork from under the floors and girders, as long as he proceeds in the way he has so far. The time of removal of the centering is the critical one and the time when accidents are most likely to happen. In many cases the forms are removed when the concrete is still quite soft; it may not have had time enough to harden or the concrete may have been spoiled while being mixed, or concrete partly hardened may have been stirred up again and mixed with additional concrete. The reasoning of the contractor will generally be, that it has had time enough to harden and that the forms and supports must come down, because they are needed at some other part of the building. Moreover, a floor that may have set for a sufficiently long time to carry its own dead load, has frequently to carry the supports and floors of one, two or even three stories above it, which are in the course of construction. The floor may not have been designed for such a load at all or at least it cannot be expected to carry several times its own dead load after so short a time, but nevertheless the contractor will strike the centering, when he should know that the collapse of the floor panel is almost inevitable.

What can be done to prevent such reckless building? Shall the careful contractor suffer for the negligence of the incompetent builder, as is now the case? Every additional report of the failure of a concrete structure tends to decrease the confidence of the public in this construction. Can something be done to make it impossible for the contractor to erect buildings of improper design or to remove the wooden supports before he has convinced himself and the building inspectors or the agents of the owner of the structure, that every part of the building is amply strong to carry the load for which it has been designed?

In my opinion failures can materially be lessened, if not entirely be prevented, by proper building ordinances which make it compulsory to use concrete of specified proportions of crushed stone, sand and cement, to use the proper kind of reinforcement in each case and the necessary amount of it. Certain standard rules should be laid down by a board of building examiners and certain types of reinforcing material should be excluded where they are not in their proper place. In addition to these points, which refer to the designing of the structure, the erection of the building should be accompanied by continuous tests of the concrete that goes into the construction and the builder should be compelled to inform himself of the strength of each column, girder, beam and floor slab before striking the forms and placing the load upon them. In the following let me explain to you what I mean by this and let me illustrate how I would like to see such building laws drawn up. In order to facilitate this I will make use of the data relating to the columns of the two collapsed structures, which I have mentioned and with which you are familiar and will show how proper ordinances can prevent similar faulty construction.

Some building ordinances speak of concrete only in a very general way; they specify a certain load "per square foot of concrete," which shall not be exceeded in the design, but make no mention of the proportions of the various substances that make up the aggregate and thus make it possible for the architect to specify 1:4:10 concrete in places where 1:2:4 or 1:3:5 would be the proper mixture to use. I have more than once heard contractors argue that, in certain walls and piers a mixture of 1:4:10 would do, when I had specified the work to be made of 1:3:5 concrete.

Moreover, the nature of the crushed stone and sand should be taken into consideration. The stone should be submitted to tests for compressive strength, so that the contractor may be sure that it does not weaken but rather strengthens the concrete. The best of all would be to have the contractor determine the voids in the crushed stone and in the mixture of crushed stone and sand, and thus to find the most favorable ratio of cement to stone and sand, as this varies with the nature of the aggregate. By these means the contractor may not only obtain a harder concrete, but in many cases considerably reduce the cost of it.

The percentage of reinforcement should be specified for the various mixtures of concrete and for varying loads, so that it may not happen again that an architect tries to reinforce a 20-in. column in the basement of a five story building by four ½ in. rods, that is to say, by less than ¼ per cent of reinforcement. The columns are naturally the points from whence the greatest disaster is to be expected, as their failure causes an entire portion of the structure to come down, while a weak girder or beam can only be the cause of the collapse of a floor panel. Therefore columns should be heavily reinforced and preferably only by reinforcement which gives ample warning of a coming disaster, as, by crumbling and scaling off of the concrete on the outside of the column. Such reinforcement is spiral reinforcement of the Considere type or expanded metal cylinders. These should be used exclusively for columns, which have to sustain heavy loads, and bars of any description should be prohibited.

For girders and beams, trussed bars should be preferred to single bars, which are simply connected by stirrups, as the former represent units which cannot be easily moved out of place in tamping the mortar into the forms.

The thickness of the wooden planks and wooden supports of the forms should be specified for each load, so that girders and beams be not deformed during the tamping of the concrete.

In the construction of floors it should not be allowed to erect the woodwork for the next floor above it on the green floor. This method of building the floors imposes too much of a load on the fresh concrete. The forms for the floors should be supported independently of the floor underneath by inclined posts, so that the weight of the forms and floor shall rest upon the columns and girders and not upon the floor below. Or in case the former method of construction is adopted, the centering should be removed only when the top floor or roof has set hard, and then the removal of the planks and supports should begin at the top and not at the bottom. so that a comparatively fresh third floor has not to sustain the load of three or four floors above it with all the woodwork between them.

The requirements of which I have spoken so far, dealt with the design of the structure or the method of erecting it. We now have to discuss such methods for testing concrete as might reasonably be forced upon the contractor in order to assure success.

From my previous description of negligent concrete work you will have seen, that it is not at all sufficient to test the cement, crushed stone and sand. The contractor may have the best materials on the ground, that can be imagined for the purpose, and yet he may make them into a weak concrete and his work may result in failure notwithstanding skillful design and proper and sufficient reinforcement. Therefore I regard it as the most important point in concrete construction, that every contrator, who undertake to erect buildings, more than one story high, should have a small shed on the grounds which is more or less equipped as a testing station according to the amount of work he undertakes.

The main equipment of such an experimental station should be a powerful hydraulic press which enables him to crush 6-inch concrete cubes. During the course of construction he should take a sample of the well-mixed concrete that goes into the construction work and should fill a mould with it at the time the concrete is being tamped into the forms. This should be done for every cubic yard of concrete that goes into the columns, girders, beams and floor slabs; it might be done less frequently with foundation work, where larger amounts of concrete are involved. The moulds should be set aside and should be numbered, so that for each test piece it is known with which part of a column or with which girder or beam it corresponds. Then before striking the forms the contractor should crush his test cubes and determine their resistance to compressive stress. This alone will tell him whether or not he can safely remove the woodwork. There should be several test cubes for every 5 or 10 feet of a column or girder, so that an average from 2 or 3 tests is obtained and that still some test pieces remain for future dates, if the strength is not found to be satisfactory, when being tested the first time, and if consequently the concrete work has to be allowed to harden for an additional week or two. Such tests would show the contractor at which part of his construction weak concrete has been used. He would have to give that special part of the building more time to harden or can remove it in time and replace it by better concrete, if he notices that the test cubes which he keeps do not increase in strength from week to week.

The figures which the contractor obtains from his test cubes submitted to compressive strength will enable him to calculate the load that a column is able to sustain. He knows by experience or from observations of competent experimenters how much he is allowed to add to the strength obtained by his tests for every per cent of reinforcement of a certain type which he has imbedded in the concrete.

Much excellent work has been done these last years in the way of testing concrete work at well equipped experimental stations, for instance by Professor Talbot of the University of Illinois, by Mr. Harding of the C., M. & St. P. Railway and by Mr. Van Ornum and others. Through their work we have received insight into the various phases of failure of beams and have been taught the advantages and disadvantages of different methods of reinforcing; briefly we have been familiarized with a subject about which very little was known up to a short time ago. To these same experimenters I wish to appeal in this paper and should like to request them to bring their highly scientific methods of testing down to the plane of actual practice. They have laboratories which are thoroughly equipped for this purpose and will be able to contribute a great deal to leading concrete construction the right way, if they only realize our wants. What we need is short and inexpensive tests of concrete and formulas which permit us to draw reliable conclusions from tests of concrete. If mathematical laws could be established which would allow us to compare figures obtained from concrete without reinforcement with those obtained from reinforced concrete, we could omit elaborate tests of complete beams and girders. For instance, it would be of great practical value to know the loads which can safely be sustained by a 10-ft. beam reinforced with steel, by a beam of the same dimensions without reinforcement and by a beam of half or one-third this length. If a certain ratio could be established between these three, the contractor could make test pieces of small beams without reinforcement, as he goes on with his construction, load them until they break, and thereby draw conclusions as to the load that the 10-ft. reinforced beam of the structure can safely carry at the time of the test.

The experiments of the above mentioned investigators enable us to properly design any part of the structure, since we know the behaviour of concrete and steel under different conditions and the effect of repetition of load and retention of load. The principles which they have established by their work are of great value to the designer. But the contractor would have to go the reverse way, if he would follow my suggestions. The only known data for him would be the figures obtained from his test pieces and from these he would have to draw his conclusions. Thereby he would check the calculations of the designer and give the only reliable proof of the safety of the construction. I realize that it will not be easy to establish rules, which will permit of drawing conclusions the reverse way; it would require a large number of comparative tests. But even approximate figures would be of great value for the guidance of the contractor until the time when every phase of this science will be fully worked out.

If a few of our large cities would make a start and adopt such building ordinances as I have suggested, smaller towns would soon follow their example and it would be known among the building public, where ordinances exist which safeguard concrete construction and where not. Then every prospective owner of a building no matter in which state or town or country place he may be, will be in a position to stipulate in his contract with the engineering firm or contractor who attends to the designing and erecting of the building, that in every detail the design and erection of the structure shall conform to certain approved building ordinances.

In order to attain the desired results the co-operation of everyone interested in concrete construction is necessary. All experimental stations equipped with the proper testing apparatus should offer their services for the sake of public welfare and every builder and contractor should in his own interest see to it that such laws and ordinances are drawn up and enforced. Only this will make concrete costruction a safe enterprise and prevent it from falling into discredit. The commissioners of buildings of our large cities would have to take the lead in this movement and to consult competent men on the subject, so that everything possible might be done to prevent failure in concrete costruction by enforcing upon the designer and contractor certain standard rules and methods of testing. If all this has been attained, reinforced concrete construction will become the most widely used method of building. But, so far, concrete is the building material of the widest possibilities and yet the most unsafe to use.

ADDENDA.

Since this paper was written, about two months ago, some additional failures of concrete structures have occurred, one of them being the collapse of the 176-ft. reinforced concrete chimney at Louisville, Ky. The disaster was due to the poorest kind of concrete and to the lack of a mechanical bond between horizontal and vertical reinforcement, or in other words, it was caused by defective workmanship and insufficient inspection.

After having listened to the account of the numerous accidents of which I have spoken, nobody will deny that there is something radically wrong with our building codes, and in fact this has been frankly admitted by a number of engineers, but so far nobody has proposed a satisfactory remedy.

Some associations have since come to the conclusion to educate people by proper literature. This is a very praiseworthy intention of course, but it will not be effective alone. For a number of years, American technical literature is not at all deficient in good books and articles on the subject, and the men who have designed and had charge of the work which resulted in failure were not necessarily ignorant of their profession. Keen competition forced them to underbid others and as a result of this, they rushed the work and became less watchful than before. Inefficient inspection, therefore, is the root of these disasters. It is not at all sufficient to have good literature and building laws which teach how to do the work or how it might have been done. The main thing is proper supervision on the part of building inspectors who understand their business and who will compel the contractor to prove to them that the work has been done in the right way. These tests should be made before removing the wooden supports or forms.

If we review the various building regulations existing in the United States we find some, for instance the building codes of New York City and of Chicago, that contain some meager information upon which a sensible engineer can base a successful design, if he properly superintends the erection of the work; this is fortunately done in most cases. But building ordinances should be of such a nature, that the erection of concrete structures is accompanied by success not only in the majority of the cases, but in every single instance. Many building regulations contain arbitrary time limits, which offer no safety whatever. The minimum time is stated during which the forms must be left in place in ordinary weather. In cold weather this time is lengthened according to the judgment of the foreman. For instance some of the rules demand: "The forms may be removed in the case of heavy walls after one to three days or until the concrete will bear pressure of the thumb without indentation." You can imagine that a concrete which will merely bear pressure of the thumb cannot be very strong, but nevertheless such a test is regarded sufficient in the case of a heavy wall. All building ordinances in the United States relating to concrete construction are deficient in the point of inspection. They stipulate that the contractor must be prepared to make tests within a reasonable time after erection, and as often as may be required. In many cases this means that the tests have to be made after a number of workmen have been killed during the removal of the forms. The tests should be made *before* the supports are removed. For this purpose it is sufficient to expose part of a column or wall or occasionally an entire beam.

If we consider the factors of safety which the various building ordinances of this country demand, we find safe figures in the case of our large cities:

For concrete in girders, beams and floors they make use of a factor of safety of 4, and for columns and piers of 6. For steel they use a factor of safety of 2, and in some cases of 3.

These figures are about the same as customary in other countries with the exception of Germany. The Prussian Government demands for beams and floors about the same factors of safety as our large cities of the United States, namely, for concrete 5, for steel 2. But in direct compression in columns and piers, they prescribe factors of safety of 10 for concrete and of 5 for steel. The latest edition of the excellent book on "Reinforced Concrete" by the English Civil Engineer, Mr. Charles F. Marsh, contains a translation of the Prussion Government regulations which are so far the most complete and most effective. In a foot note, Mr. Marsh comments on the factor of safety of 10 demanded for concrete in direct compression and says: "This factor of safety is much too large; a factor of 5 is quite sufficient." In this remark he may be correct as far as Great Britain is concerned, but in the United States under present conditions no factor of safety can be too large, since supervision is absolutely inadequate in this country, as the many accidents prove. That the Pression Government demands so high a factor of safety for the designing of columns and piers, certainly shows much forethought. They thus protect the most, those parts of the construction from which the greatest amount of disaster is apt to result. Moreover, to severe demands in the design of a structure, the government of Prussia adds the most rigorous inspection. The building inspectors thoroughly examine every column, girder and floor slab before the woodwork is removed and thus prevent failures due to the too early removal of the forms, which is the most common cause of disaster in the United States. Furthermore, European builders are allowed to erect only one story at a time and to start the next only after the building inspectors have made sure that the first story is sufficiently strong to carry the load.

The governments of all countries belonging to the "International Society for Testing Materials" have tried to standardize building methods during the last twenty years. However, it will take a long time yet before definite rules can be laid down for concrete construction, as this youngest branch of the building industry is still in its early development and as the principles governing it are not yet fully established. In the meantime, until this type of construction shall be thoroughly understood, other countries successfully prevent failure by proper building ordinances and a very rigorous inspection during the course of erection, and this country should possess similar building laws and an efficient inspection which would obviate disaster.

Building ordinances for concrete construction that are found to be effective in other countries, can not be simply copied and be applied to this country. Even if this country should adopt building ordinances as severe as those of European countries, concrete construction would not be much safer than it is now, unless such ordinances be accompanied by laws which compel the contractor to make continuous tests of the concrete in the way I have suggested.

Prof. A. N. Talbot, M.W.S.E. *(by letter)*: The statement in Dr. Michaelis's paper that "tests of concrete should be made during the progress of the construction of the building" is an important one. The writer has long felt the desirability of a requirement that tests be made of the concrete actually put in a structure and is now investigating a method which he hopes will be serviceable for this purpose. In connection with the numerous tests of beams, T-beams and columns in progress at the University of Illinois, he is including a set of flexural tests on test beams of plain concrete, 6 by 8 in. by 3 ft. span and loaded at the one-third points, this loading being chosen to further bring out the weakness of the test pieces. The beams are made from the same mixture of concrete as are the reinforced concrete beams and columns, and the test is made at the same age. The concrete varies from very rich to very lean mixture, and the age of test runs from 4 to 60 days and longer. The results will be compared with the strength of the reinforced test pieces. It is the writer's idea that these beams may measure the quality of the concrete and in many ways will tell the strength of the reinforced concrete structure. The modulus of rupture is very close to the tensile strength and tensile strength is indicative of many of the purposes and requirements in reinforced concrete beams and in some respects indicates the compression quality also. Compression tests are made on test pieces from the same mixtures. If these results prove to be sufficiently accurate, the writer intends to suggest these flexure tests of concrete as a method of finding whether the concrete which goes into a building is composed of proper ingredients and properly mixed. Of course, this will not safe-guard the further opportunity for weakness in the placing of concrete in forms nor will it give the freedom from stress before a sufficient set is obtained, which is necessary to secure a building of proper strength. The freedom from stress during setting is, of itself, a very important item.

NOTE—At the conclusion of reading the above paper, the hour was so late there was no time for any discussion by those present, nor has this subject been brought forward at any meeting since then.

PUBLICATION COMMITTEE.

THE APPLICATION OF THE STORAGE BATTERY TO LIGHTING, POWER AND RAILWAY SERVICE.

Read before the Electrical Section, Mar. 15, 1907.

By J. M. S. Waring.

In this paper I have divided batteries for lighting, power and railway service into two general classes under the headings, (A) batteries for railway and power service; (B), batteries for lighting service, and have subdivided each of these classes under two sub-headings. I have then shown the functions of the storage battery for the classes of service falling under these sub-headings. These divisions and subdivisions are shown by a diagram on the following page:

For the purpose of this discussion, I have divided the paper into two parts, the first part treating of the means of controlling the charge and discharge of batteries; the second part treating of the results accomplished by the batteries in their various applications to lighting, power and railway service.

Part First.

In order to properly comprehend the method of regulating battery charge and discharge, it is necessary to be familiar, first with the general characteristics of a storage cell, and second, to have a thorough conception of the method of maintaining some predetermined charge or discharge of the cell for some fixed period of time.

Sketch 4 illustrates in a general way the discharge curves of a cell at various rates, and also a charging curve at the normal or eight hour rate. In discharging a cell at any rate, the voltage at the beginning will drop rapidly; then the drop in voltage will be comparatively slight over a long period until near the end of the discharge when it will again drop rapidly. What is known as the limiting discharge voltage of a cell at any rate is a point just over the break in the curve. If the cell were allowed to dicharge beyond this point, at the same constant rate, its voltage in a very short time would drop to zero. During the charge of the battery at any rate, the voltage will rise rapidly at first, then less rapidly until near the end of charge, when it will again rise rapidly to a point generally known as the maximum charging voltage. If the charge is continued beyond this point, the voltage will remain practically constant. As soon as the flat part of the curve is reached, the cell is completely charged, and the further passage of current will give practically no additional capacity.

- (A) Railway & Power Service
  - (1) P.H. or S.S. Battery
    - Current Regulation
    - Peak Work.
    - Current Reg. & Peak Work.
    - Emergency Reserve.
  - (2) Line Battery
    - Current Regulation.
    - Peak Work.
    - Current Reg. & Peak Work.
    - Improving Line Voltage, Copper Saving, Offsetting Rotary S.S.
    - Emergency Reserve.
- (B) Lighting Service
  - (1) Central or S.S. Battery
    - Peak Work..
    - Emergency Reserve.
    - Voltage Regulation.
    - Equalizing.
  - (2) Line Battery (Battery S.S.)
    - Peak Work.
    - Emergency Reserve.
    - Voltage Regulation
    - Improving Line Voltage, Copper saving, Offsetting Rotary S.S.
    - Equalizing

A cell on open circuit will show approximately 2.08 volts, which is practically independent of the state of charge of the cell. This is frequently known as the floating voltage of a battery; in other words, a cell of storage battery, if connected across a potential of 2.08 volts, will neither charge nor discharge.

In order to maintain a constant rate of charge or discharge from a storage cell, the e.m.f. of the source of supply or demand must, throughout the charge or discharge of the cell, be increased or decreased so as to conform to the charge or discharge curve at that particular rate. As an illustration, let us suppose it is desired to discharge a cell at a rate of 100 amperes for eight hours, assuming that to be the capacity of this particular cell; if it is first con-

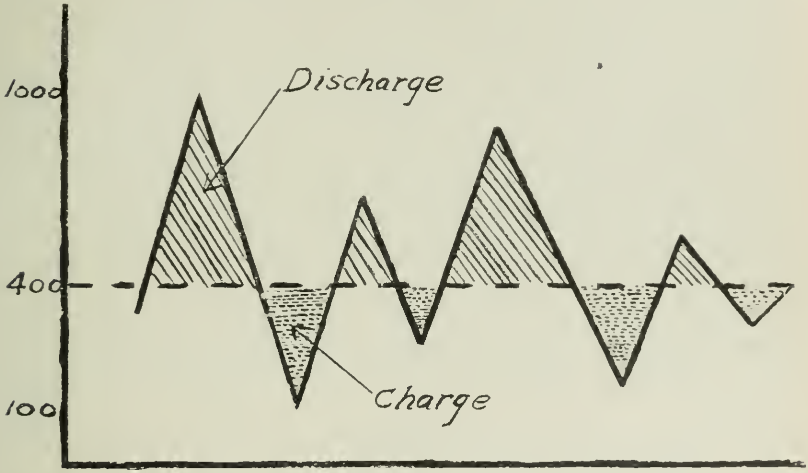


Fig. 1.

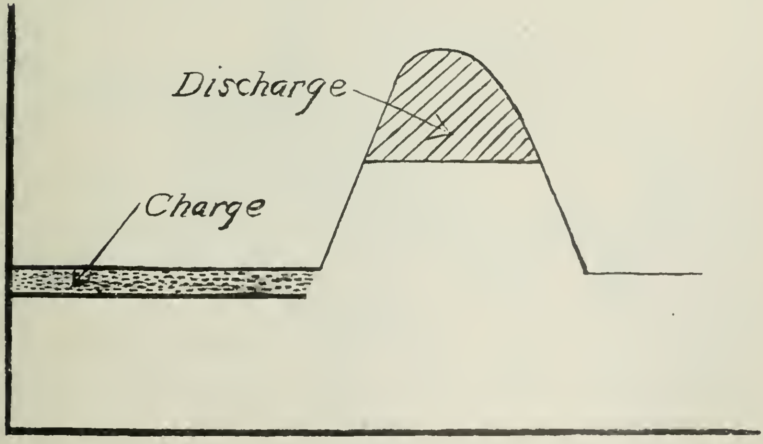


Fig. 2.

nected across a potential of 2.08 volts, it will neither charge nor dicharge. If this potential is instantaneously reduced to 2.04 volts, the cell will discharge at a rate of say 100 amperes, more or less, according to the state of charge, temperature, etc.: that is, the instantaneous drop in cell voltage will be 0.04 volts when discharging at a rate of 100 amperes. This first drop in voltage is practically entirely due to the internal resistance of the cell. As the resistance of the cell in question is approximately 0.0004 ohms, under the above conditions the cell must be connected across a potential of 2.04 volts, when it will begin to discharge at a rate of 100 amperes. As the discharge goes on, the e.m.f. across the cell must be reduced until at the end of eight hours it will have reached the final voltage of that particular discharge rate; that is to say, in order to keep the discharge of this battery constant at 100 amperes for a period of eight hours, we have gradually reduced the voltage of the circuit to which the battery is connected so that the curve of voltage maintained across the cell throughout the discharge is the eight-hour discharge curve of the battery. If these points are thoroughly understood, there should be no difficulty in understanding the operation of such auxiliary apparatus as is necessary for the control of the battery. Battery regulation may be generally divided into two classes, automatic and hand regulation.

AUTOMATIC REGULATION.

In cases where it is necessary to make the battery charge or discharge suddenly and for short intervals of time, automatic regulation is required. This is necessary in batteries classed under the headings, "A 1" and "A 2," where current regulation is to be ef-

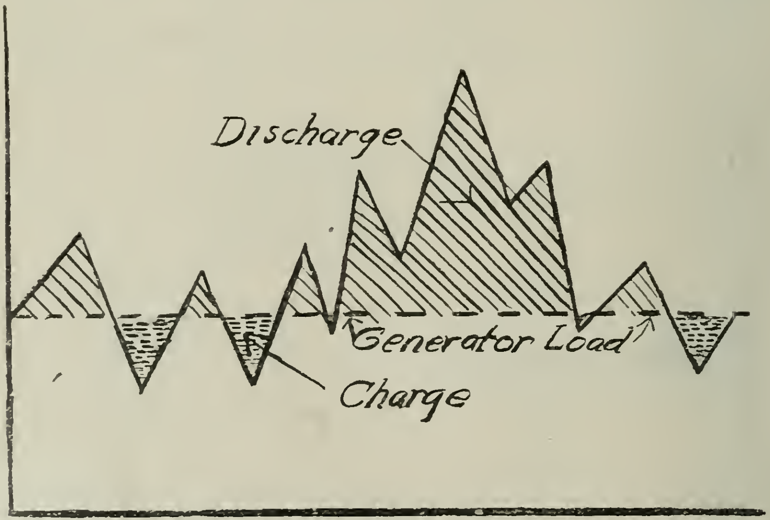


Fig. 3.

fected. As a matter of fact, practically all batteries in railway work, whether power house, sub-station or line batteries, are required to give current regulation, even if primarily installed for some other purpose, such as peak work. Therefore, in this class of service, the auxiliary apparatus must be such as to automatically regulate the charge or discharge of the battery, causing it to discharge at intervals of heavy load, and charge at times of light load. This is usually accomplished by means of a booster, although in some line battery applications no booster is used, as will be explained later. In power house or sub-station batteries, the type machine in most general use is known as the regulating shunt booster. The operation of this is as follows:

Referring to sketch 5, the battery in series with the armature of the booster is connected directly across the generator or rotary bus. The booster in this case is a specially designed shunt wound machine. Let us suppose that the average load on this sub-station (sketch 1) is 400 amperes, and that it is subjected to heavy and sudden fluctuations of load, varying from a maximum of 1000 amperes to a minimum of 100 amperes; the fluctuation above the average therefore amounting to 600 and the fluctuation below amounting to 300 amperes. The function of the battery in this case is to relieve the station of these fluctuations, maintaining a constant load on the generator or rotary approximately equal to the average of 400 amperes.

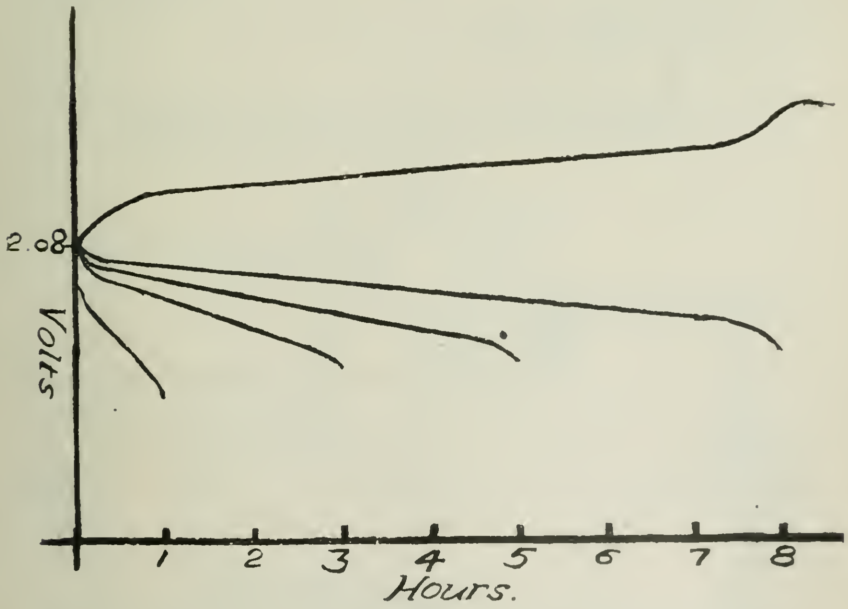


Fig. 4.

As we have already found from the discussion of the characteristic of a storage cell, in order to make this battery discharge at a predetermined rate of 600 amperes for a predetermined time of, say, 15 seconds, the voltage supplied across the battery terminals must be dropped an amount equal to the drop in battery voltage under this discharge and for this period of time; in other words, let us assume that this particular battery, when discharging at a rate of 600 amperes for 15 seconds., will drop 10 per cent. in voltage. Since the floating voltage of the battery is 600 volts, its minimum voltage under this discharge will be 540 volts. The booster must, therefore, give 60 volts, and its potential must be in a direction opposite to that of the station bus, so that the required 540 volts will be applied across the battery terminals. In order to make the battery *charge* at a predetermined rate for a predetermined time, the booster must generate a voltage equal to the increase in battery voltage above its floating point, and the potential of the booster in this case will be in the same direction as the bus potential, thus giving the necessary charging voltage across the battery terminals.

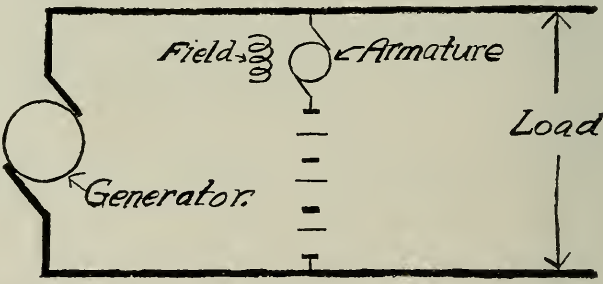


Fig. 5.

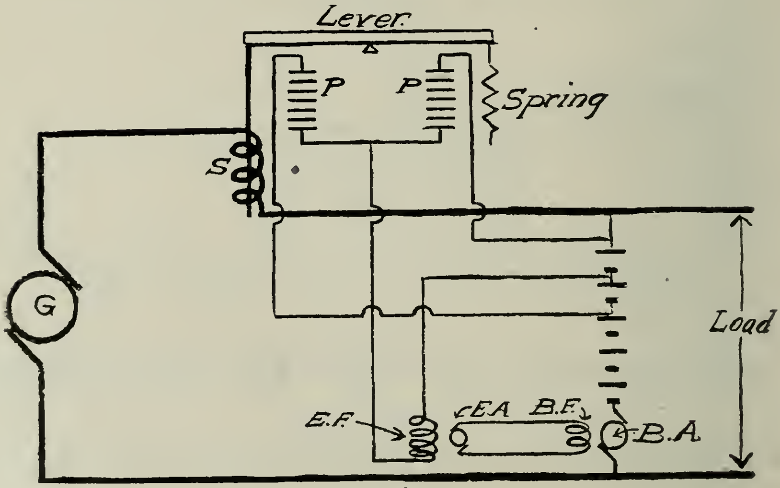


Fig. 6.

These automatic changes in field excitation and the reversals of the field are, with a regulating shunt booster, accomplished by means of a carbon regulator. This regulator (sketch 6) consists of two piles of carbon discs connected in series across a part of the battery, this battery potential causing a continued flow of current through the carbon piles. The booster field is excited by an exciter, the field of which is connected from a point midway between the carbon piles to a point on the battery midway between the connections of the carbon piles to the cells. A lever is carried on a fulcrum located between the two piles. From one end of the lever is suspended the iron core of a solenoid, S, which solenoid carries the output of the generator; at the other end is an adjustable spring which, when the battery is required for current regulation only, is so adjusted that its pull will exactly equal the pull of the solenoid at the time of the average load on the plant. The operation of this regulator is based on the principle that the contact resistances between two carbon surfaces is decreased by pressure. When the average load on the station obtains, and the pull of the spring exactly balances the pull of the solenoid, the resistances of the two piles of carbon are the same, and no current flows through the fields of the exciter. Now, if the current from the generator increases by a very small amount, the increased pull exercised by the solenoid will compress one pile and reduce the pressure on the other, thus destroying the equilibrium and causing current to flow through the exciter field in such a direction as to give the necessary excitation of the booster field in the proper direction for battery discharge. Conversely at times when the load on the station is less than the average, a slight decrease in the current through the solenoid compresses the *other* pile, thus causing a reversal in direction of the current flowing through the exciter field, and giving the booster an e.m.f. in the direction of charge.

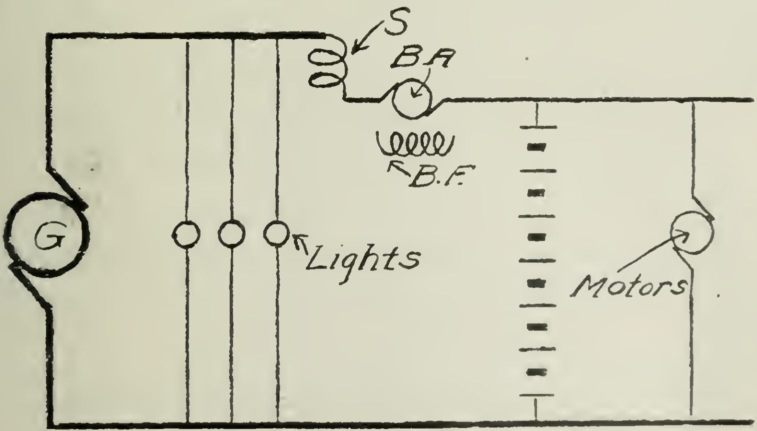


Fig. 7.

Under the heading "Line Batteries," automatic regulation may be effected, first, by means of a booster; and, second, by means of the line drop, the battery in the latter case floating directly across the line without any auxiliary apparatus. In the first case, the type of booster used is a specially designed compound wound machine (sketch 8). When the average load obtains on this particular line, and therefore the average voltage exists at the battery, the battery should float; that is, should neither charge no discharge, and the booster voltage at that time will be zero. Now if a heavy load is applied to the line, a slight drop in the line voltage at the battery will start a discharge from the battery; this discharge passing through the series fields of the booster builds the voltage of this machine up to the required amount.

In the second case of Line Battery operation, which is illustrated by sketch 9, while the average line voltage obtains at the battery, the battery floats; a heavy load applied to the line causes a drop in voltage at the battery, thus causing a batttery discharge to the line. It is obviously impossible by this means to relieve a line of the same percentage of fluctuations as can be accomplished by the use of a booster in conjunction with a battery, as the characteristic of the battery in the latter case is similar to that of a shunt wound generator applied at this point, while in the case of the line battery operating with a booster, a practically constant potential is applied across the line at the point where the battery is installed.

In certain classes of power work where the load consists of a steady lighting load, and a fluctuating load, due to the operation of motors, another type of booster known as the constant current booster is frequently used. This is illustrated in sketch 7. A carbon regulator solenoid in series with a booster armature is inserted

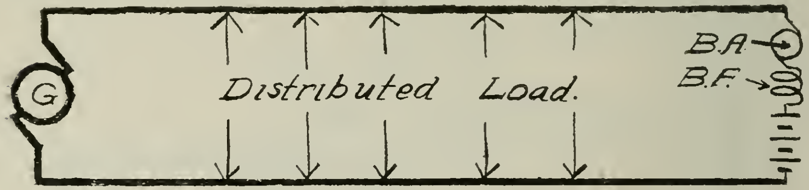


Fig. 8.

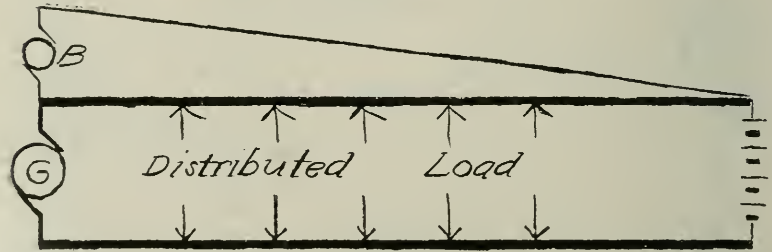


Fig. 9.

in the bus between the steady load and the fluctuating load, the battery being connected across the fluctuating bus. This booster passes continually from the generators the average motor load; its field is varied with the load by means of a carbon regulator, which was described in the case of the regulating shunt booster. By means of this booster, the potential of the battery bus is made to vary in acordance with the battery characteristic. In this case the power bus voltage varies with the battery of course while the lighting bus voltage remains constant.

The above covers in a general way the more common methods of obtaining automatic regulation of battery charge and discharge.

HAND REGULATION.

In cases where the battery is required to carry a sustained peak, as illustrated in sketch 2, that is required to discharge continuously over a comaparatively long period, with little or no compensating charge during this period, the control of the battery and discharge is accomplished by hand regulation. As stated above, nearly all batteries in railway or power service are required to give automatic regulation, on account of the sudden fluctuations of load. For this reason a booster is required with practically all railway and power batteries. If, in addition to regulating the fluctuating load, the battery is required to give a sustained discharge (as shown in sketch 3), that is accomplished by raising the booster voltage in the direction of discharge from time to time during the peak, as the load increases and as the battery voltage falls off, this being accomplished by hand operation of the field rheostat of the booster.

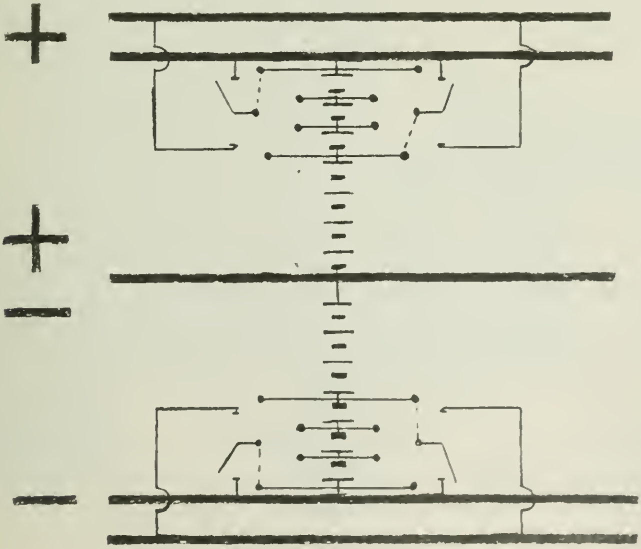


Fig. 10.

In case of lighting batteries, automatic regulation is seldom required, owing to the slow and long-sustained changes in load; therefore, booster regulation is not necessary on discharge, and the regulation of the *discharge* is usually controlled by means of end cells. This is illustrated in sketch 10. In this case let us suppose the main battery is floating across the bus neither charging nor discharging. Then let us assume that, with a discharge at a certain rate, an initial drop of ten volts would occur in the main battery. In order to compensate for this drop, such a number of end cells must be placed in service that the voltage of these end cells, with the battery discharging at this particular rate, will be equal to the drop of ten volts in the main battery. On sketch 10, I have shown two end cell switches on each side of the system. Frequently in Edison work two or more bus pressures are maintained. The battery with this system of connections can be operated on two spearate busses, the end cell switch on one side being cut back and the other run forward so as to give the desired voltage on the two busses. In larger service on Edison work, charging is accomplished by means of a shunt wound booster. This booster may be connected in series with one of the end cell switches, the other end cell switch being connected directly to the bus and cut back more and more as the charge goes on, so that the battery may be kept floating directly on the system even while charging.

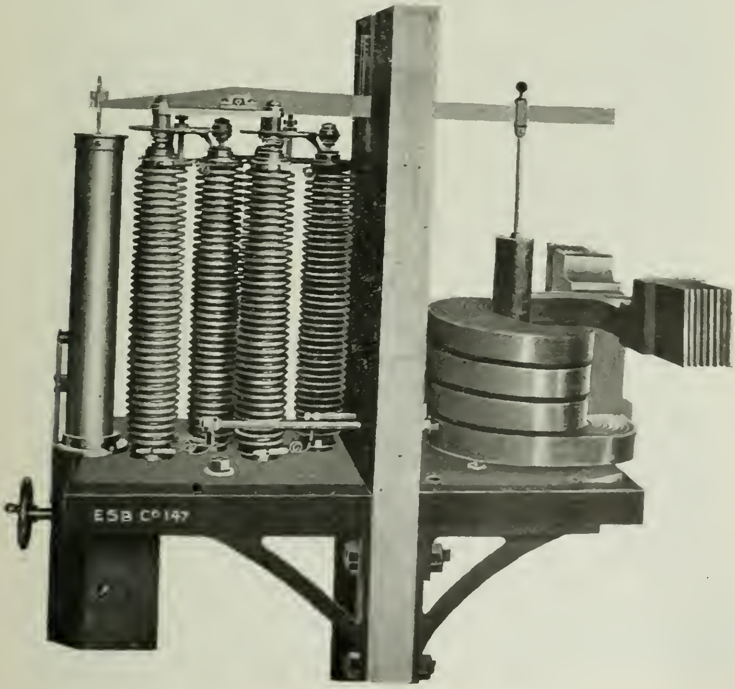
PART SECOND.

With respect to the functions of the storage battery: First, in railway service; I might say that on the smaller railway systems the principal function is usually that of current regulation; that is to say, relieving a plant or sub-station, or both, of fluctuations of load and maintaining a constant load on the generating apparatus and rotaries. As the systems increase in size, peak work by batteries become more and more important, and in the largest systems it is distinctly the principal feature of the battery.

In the case of d.c. railway power houses, the batteries by relieving the station of fluctuations allow the engines in service to operate at a steady and economical load. In practice, if we assume that the heaviest fluctuating load that small d.c. unit will carry, without constant trouble, is twenty-five per cent. in excess of its continuous rated capacity, and assume that the momentary fluctuations of load are double the average, it is evident that the generators, if carrying these fluctuations, will not work at a load factor above 62.5 per cent. It is, therefore, obvious that by using a battery in this class of service the capacity of the station can be materially increased, and frequently the load factor of the units in operation may be greatly improved as the fluctuations are often of such extent, as to necessitate the operation of more than one unit without the battery. The battery by obviating the necessity of the operation of, say one unit, of course, eliminates the constant losses incident to this unit, and increases the efficiency of the remainig units by improving their load factor, thereby permitting the station to give the same output with less loss, or a greater output with practically the same loss.

The losses due to conversion in the battery are almost negligible as compared to the increased economy of station operation, since the current converted is but a small percentage of that generated, the main point being that the current is stored when not needed, and given out at a time when it will be of the greatest value. In the case of batteries installed for regulating work in sub-stations, not only the rotaries, but static transformers, high tension transmission lines, alternators, engines and boilers, are relieved of the load fluctuations, thus insuring a load factor on the system closely approaching ideal conditions, and frequently resulting in a reduction in the number of boilers, engines and rotaries necessary for the operation of the system.

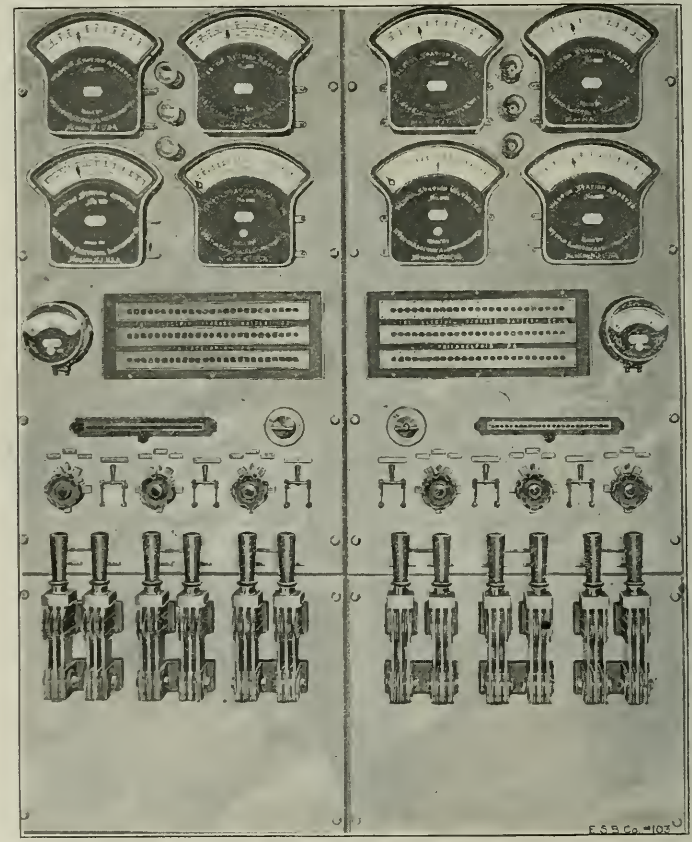
In small water power plants, the regulating feature of the battery is exceedingly important as the capacity of a water power plant for a given speed is fixed first, by the maximum demand, which in many cases is two or three times the average. Therefore, the battery by relieving the load fluctuations in this case permits the operating company to get the maximum value and output from its water power



The Carbon Regulator

the battery also acting as an excellent governor for the water wheels. In water power plants supplying a fluctuating railway load and a lighting load, or in rotary sub-stations furnishing these classes of service, the battery eliminates the fluctuating voltage conditions on the lighting service due to the variation in the railway load.

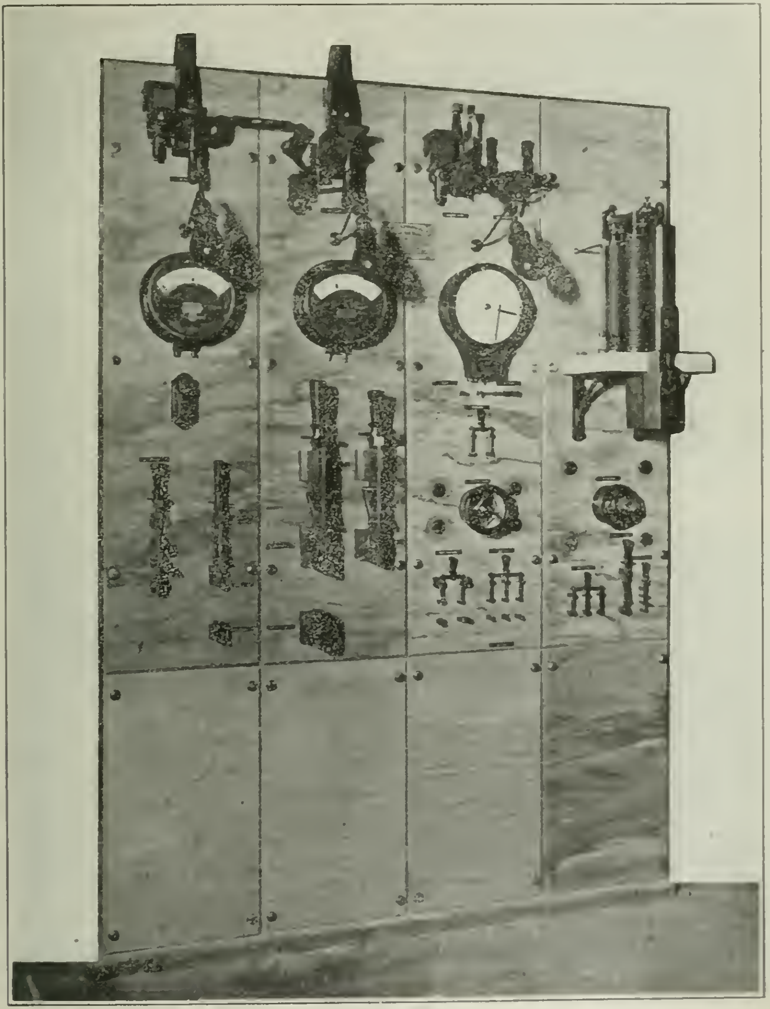
On suburban and interurban electric railway lines, the line batteries will frequently save more than their cost in feed wire, which would be necessary to produce the same line voltage conditions, or where the average load of a line is small, the battery will often offset a rotary sub-station. By the installation of a booster at the power house in conjunction with a line battery as is shown in sketch 9, the discharge and charge of the battery may be controlled by a hand-adjustment of the booster rheostat, no regular attendant being necessary at the line battery, while the item of attendance in the rotary sub-station is considerable.



Battery Switchboard for Edison Three-Wire System.

The value of the line battery as against additional copper, lies in the fact that the copper with the battery has only to carry the average current, while without it sufficient copper must be installed to transmit the maximum current, with a drop in voltage which will not be prohibitive to good operating conditions.

In larger railway work, such for instance, as the surface and elevated roads in large cities, there is a pronounced peak caused by the traffic to and from the business center, the length of this peak varying from two to sometimes three or four hours. Batteries

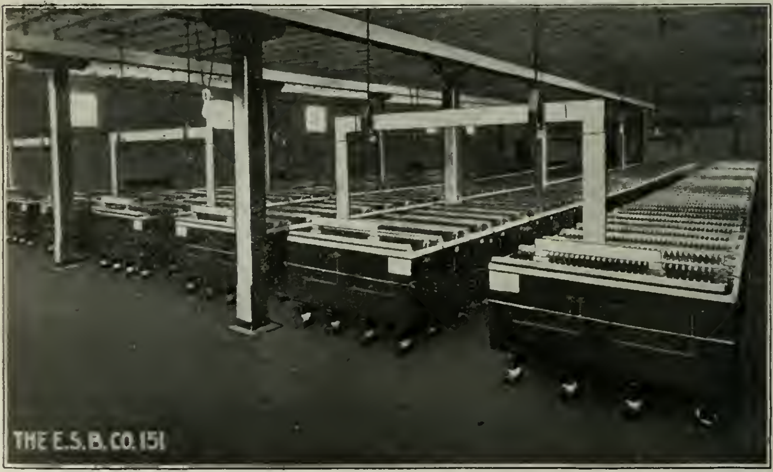


Battery and Booster Switchboard for Railway Power House or Sub Station (showing Carbon Regulator on end panel) installed in the power house to relieve the station of these peaks greatly improve the load factor and materially reduce the cost of operation of the station, besides offsetting an equivalent or even greater amount than the cost of the battery, in generators, engines and boilers. In a number of cases, such as the elevated roads in Chicago, it has been advisable to install the batteries on the line rather than at the power house. In this location they not only relieve the power house of a sustained peak during the morning and evening, but also relieve the feeder system of this peak. In a case that I have in mind in Chicago, the cost of the battery was entirely offset by the amount of copper that would have been necessary if it had not been installed.

Where operating companies purchase, instead of generating their own electric power, the rates are usually on a maximum demand basis, and it is, therefore, to the advantage of the consumer to keep down the peaks. In a number of instances the annual interest and maintenance of storage battery installations have been more than offset by the annual depreciation in the power bills, due to the reduction of the power demand.

The emergency value of the battery in railway service depends on the proportion of battery capacity to the load, and besides this, depends largely on the class of service; for instance, batteries in sub-stations on interurban work, even if installed for regulating work only and of comparatively small capacity with respect to the generator and rotary equipment, have at least sufficient capacity to move the cars in the event of shut-downs in the sub-stations, to the nearest station, thus obviating the possibility of cars being stranded in the country between towns.

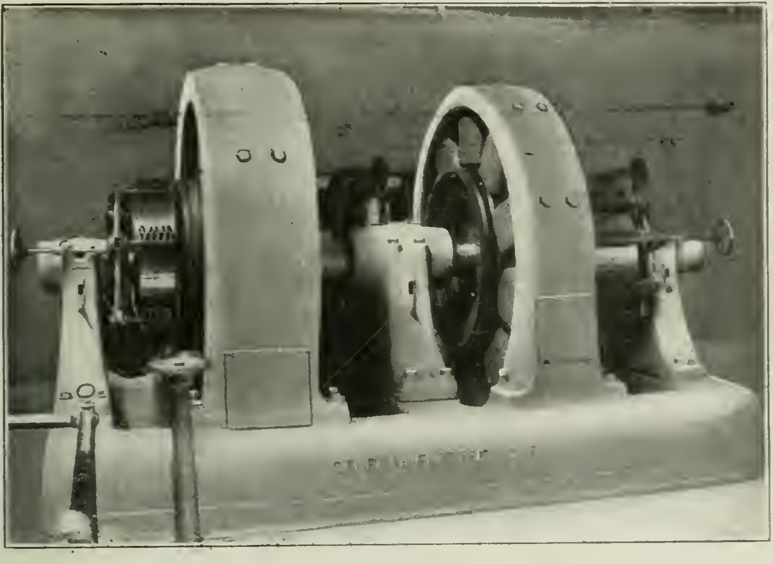
In lighting work, such as the Edison service in our large cities,



Railway Battery.

the same arguments for storage batteries for peak work would hold as in railway work.

In the case of sudden, unforseen demands for power, such as frequently occur on dark days, the batteries are instantly available for furnishing power until additional generating apparatus can be placed in service, thus not only insuring satisfactory service conditions, but often effecting a material saving in fuel, by obviating the necessity of operating additional boilers and generating apparatus in anticipation of unforseen loads.



Regulating Booster.

Battery for an Edison System (showing end cell connection).

DISCUSSION.

Mr. P. Junkersfeld, M.W.S.E.: I have been much interested in Mr. Waring's paper and the manner in which he has presented it. I doubt whether many people who ride on our surface and elevated railways and who have electric lighting service, realize the value of the storage battery. I believe it has been called "the watch dog of electrical service," and it is very aptly termed so. It is something that lies there quietly in many sub-stations and as long as the harness is on it is ready for work.

The storage battery has, as Mr. Waring pointed out, a number of advantages. It can be used for regulation or for peak work. In lighting systems in large cities it is used very largely for emergency service, and for that reason the companies feel that they want to have the batteries fully charged all the time, even though sometimes there might be economy in discharging.

The battery also ought to have quite a field in large manufacturing enterprises, where the cost of power is a very small part of the total cost of production, but where, you might say, everything stops when the power is off. That is a feature which will be recognized more and more as time goes on, not only for manufacturing establishments operated on direct current, but also on alternating current. Developments, I am informed, are well under way with which it is feasible to get this valuable storage battery protection for alternating current service.

There is another application of the storage battery that Mr. Waring has not mentioned, and which I hope he will tell us about; that is, the use of storage battery locomotives for industrial work—intermittent switching in manufacturing establishments and large yards—a class of service for which the battery seems particularly well adapted. Of course, it would have its limitations if the switching were of such character that heavy loads must be moved continuously, but there are many cases where it should find proper application.

Mr. Waring: The use of the battery in that class of service is largely dependent on the work that the locomotive has to do, and on the charging facilities. In a switching yard, where the work required would be continuous for a period of seven or eight hours, with no time for charging during that interval, the weight of the battery, besides its cost, would probably be prohibitive. In the case of a certain manufacturing establishment, where they have a switching yard, it was found convenient to have one of these locomotives for shifting purposes. In that service the car runs from one end of the yard to the other in about two minutes; it takes another two minutes to unload; then goes back, and this is kept up for the entire day. We have suggested in that case a shoe on the car, and as soon as the battery gets to the end of the line the charging could be done while the cars are being unloaded. The run is so short that in this case the battery is alternately charging and discharging for short intervals, there is therefore very little battery needed for this service. In a case of this kind the battery can be kept down to a suitable size with little expense.

While I have the floor, I might say that there is one point I did not cover, simply because of lack of time and the fact that it is a lengthy subject. Mr. Junkersfeld has referred to this—the application of the battery to a. c. work. The battery in that class of service, is in its infancy in one sense, still, during the past two years, the company with which I am connected has installed several batteries for this work. We have closed a proposition with the Indiana Steel Co. in connection with the new Gary plant. In one of their rolling mills the load was to vary from 4,000 H. P. to 14,000 H. P.; the fluctuations coming on with very great rapidity. The power house at Gary will consist of seven alternators and two d. c. power machines. They will supply d. c. at 200 volts and also alternating current. The batteries on this system will be connected to the d. c. bus through a booster, such as shown on sketch 5. To that extent it is exactly similar to a battery in a railway power house. It will also be connected through a specially designed rotary and transforming apparatus to the a. c. mains, and by means of special regulating devices which are governed by the fluctuations in the a. c. load, the battery can be made to discharge into the rotary at the heavy load, or take a charge from the rotary at times of light load on the alternating system. A similar installation to this is at the Youngstown works of the Carnegie Steel Co. There is also another a. c. plant now in service in the state of Washington. In that case the source of supply is three phase 60,000 volts and 60 cycles. The road is a single-phase road, operating at 25 cycles. The battery is installed in a frequency changing sub-station. In this station they installed one 60-cycle alternator, and one 25-cycle alternator, on the same shaft with a d. c. machine. The battery is connected across the d. c. machine and is regulated by a carbon regulator, as described, only in this case the solenoid of the carbon regulator is in the a. c. supply mains. A slight increase going through the solenoid causes a battery discharge. The d. c. machine then acting as a motor driven by the battery and giving the necessary excess power to the shaft of the motor generator set. Conversely, at times of light load, the d. c. machine acts as a generator and supplies power to charge the battery, thus keeping a practically constant demand on the supply line.

A Visitor: Where there is a very small leak in a cell, what is the best way of fixing it?

Mr. H. M. Beck: For the actual tank repair there is no temporary way. Our practice is to burn a patch of lead right across over the hole. The cell is cut out for the time being, and the sooner the better. Naturally, the acid gets into the wood work and rots it. There is no temporary means of repairing a leak.

Mr. G. H. Atkin: We are very glad to have a chance to tell the members of this Society how much can be done in electrical work in an engineering way, and also in a commercial way, by putting in a storage battery system. I hope that those present will not hesitate to ask questions from the engineers here on this very important subject. I think you can learn a good deal that you ought to know about batteries, and if it were a question of trying to sell you a battery system I should feel a little more in my element in explaining their conditions, their manufacture and their care.

Mr. C. A. S. Howlett, M.W.S.E.: Mr. Waring touched on the plant at Gary, Indiana. If he would tell us the approximate size of the storage battery equipment. I think it would be of interest to those present.

Mr. Waring: It is a "71 R.," about 250-volt plant. There are two batteries to go in parallel, each 250 volts and each having a capacity of 4200 amperes for one hour. In the beginning the battery plant will have a capacity of 8400 amperes for one hour, and if the present plans mature, the expectation is to double this.

Mr. F. M. Davis, JUN. M.W.S.E.: It is generally understood that in most cases the ultimate size or capacity of the telephone plant cannot be definitely determined at first, and that for storage battery plants for telephone exchanges, it is often customary to count on an ultimate equipment much greater than is necessary for the initial equipment. The question is to determine how much growth it is practical to count on in the initial equipment, and to what extent it is advisable to leave the ultimate equipment for future addition. As I understand it, it is cheaper to put in a given number of plates in the initial installation, than to put in part of them at first and add to the installation afterwards. There is an extra expense in adding later on. Moreover, there is a slight irregularity of chemical action immediately after the addition, due to the fact that part of the plates have been in use and part are new. To what extent is it advisable to put an investment into extra plates in the initial equipment in order to save a greater extra expense in adding them a year or two later?

Mr. Waring: As far as expense is concerned, the only additional expense the purchaser would be put to by installing new plates later on would be the additional labor expense of the second installation. Assuming that the plate prices are the same, it would be slightly greater than if installed originally, but in a battery of any material size this would hardly be considered.

Another expense would be, if the battery had been in hard service for some time, the grouping of the old plates, but as far as this cost is concerned, it is hardly worth considering in a large installation. As far as the operation is concerned, there would be no trouble from putting in new plates. Of course if one were expected to put in this addition, within short time, say a year, he would be justified in providing for it in the initial installation. But unless this were the case, it would be better to put in the increase later.

Mr. E. N. Lake, M.W.S.E.: I would ask if there are any figures showing the difference in efficiency between the two plants when using the rotary and when using the motor generator.

Mr. Waring: I have no definite figures, although I expect very shortly to have some. But one thing is very apparent: that is, with the battery on regulating work the losses are small as compared with the savings the battery effects. One thing is evident; if you take a battery doing regulation work, you are working at the left hand end of these curves. Your battery is dropping off in voltage only a small amount. In regulating work, the battery can work up as high as 90 per cent. efficiency.

Mr. D. W. Roper, M.W.S.E. : Mr. Waring in describing the methods of using batteries for different classes of service, has stated that it is customary for lighting stations to use the end cell method of regulation. Some years ago, at the International Electrical Congress in St. Louis, a very distinguished European engineer made some remarks on this subject, and spoke very highly of the English method of regulating by means of a booster. I would like to ask Mr. Waring what has caused this difference in the English and American practice?

Mr. Waring: That is a subject that I have not gone into at great length for the reason that in America the practice of regulation for end cell is absolutely standard. I think Mr. Junkersfeld can give us some information on this subject.

Mr. Junkersfeld: It is the practice in England, to a large extent to discharge lighting batteries through boosters. One of the reasons, and perhaps the chief reason for not using a booster in this country, is that American engineers feel that the battery is, in a large measure, a reserve; that being the case they want to have no moving apparatus between the battery and the line, or at least the smallest amount possible. If the booster is used, it is simply another link in the chain and one that may give way. With the end cell switch method, the batteries are connected directly to the bus bar, and there is less chance of anything giving way.

From the point of operating economy and of first cost, that matter was investigated somewhat here in Chicago, within six months, after the discussion in St. Louis referred to. Mr. Roper was one of the two men who were delegated to make that investigation, and he can probably give you some of the results in detail of that investigation.

Mr. Roper: In asking the question I was expecting to get a somewhat more extensive opinion from the .storage battery engineers on this subject.

The investigation of which Mr. Junkersfeld speaks was made for the purpose of obtaining a comparison of the investment and operating cost as well as such operating features as could be learned with a limited experience. A battery was operated by each of the two methods for a period of several months and a careful record was kept of losses involved in charging and discharging the battery. The first cost of an installation, using the booster method of charging and discharging is somewhat less than the installation of equivalent size, using a booster for charging and end cell switch for discharging.

The former method has, however, considerably greater losses as the booster operated while the battery is discharging and at other periods when floating, as well as when the battery is being charged. The operating cost of the reversible booster method will therefore be greater than for the end cell switch method and this difference will increase with the use of the battery.

In order to obtain information as to what constituted the average use of a battery, we obtained figures from the leading American users of batteries for lighting work, and found that the annual cost of the end cell switch method of discharging is less than the reversible booster scheme for nearly all conditions of American practice. If, instead of using a booster for charging the battery, arrangements were made for installing a generator, or a rotary which could be operated at a sufficiently high voltage to charge the battery, and thus save the installation of the booster for charging purposes, the end cell switch method would be cheaper than the booster method under all American conditions.

Mr. Waring: I would ask Mr. Roper, in the comparison that was made between the end cell switch method and the booster method, what ampere capacity was figured on for the booster? Suppose you had a battery which was rated at 1,000 amperes for one hour; what booster capacity did you figure on in that comparison?

Mr. Roper: In order to obtain the actual figures on that point, we assumed that the booster would be called upon to carry the capacity of the battery—the one-hour rate for one hour—and it was also specified that the booster should be able to carry the 20-minute rate of the battery, for 20 minutes. The figure on the cost of the booster was an actual quotation from a manufacturing company.

Mr. Junkersfeld: I might explain regarding this question that in England the battery is in most instances not connected to the system 24 hours a day, as here. They start up and run during their peak, and then shut it down again. Furthermore, instead of trying to maintain the service, as Mr. Waring has indicated, in England there is usually an overload circuit breaker on the booster, and if a short circuit on the system is heavy enough to trip the breaker, the electric service is interrupted. In this country an effort is now made to keep the storage battery connected to the bus bars at all hazards. In England the standard of electric service is improving, and as it improves they are getting around to this end cell switch method of control, which allows them to leave the battery on 24 hours a day if they wish, and which they cannot do so economically with the booster.

Mr. Beck: In regard to this subject of the booster, there is one case which we take great care to safe-guard. If for any reason the motor of the booster is thrown off the line (through its circuit breaker, or otherwise), and the line voltage should drop considerably, there might be a heavy discharge from the battery through the generator end of the booster. Should the booster field be close to zero, we would have a case of a motor operating without any field, and there is danger of its running away, because the regular motor being off the circuit there is nothing to hold it back. As long as the motor is on the circuit, if you try to speed the booster up beyond a certain speed, the motor will act as a generator and hold it back. As a protection we use two means. In the first place, we put a circuit breaker on the motor as well as on the booster, and these two circuit breakers are connected either mechanically or electrically, so that if the motor breaker goes out it automatically throws out the battery also.

The second protection is a speed limiting device similar to the type used on rotaries, which is put on the booster shaft, and acts at a certain per cent. above the normal speed.

Another case is with lightning. A battery in itself is a very non-inductive path for lightning, and the result is that it seems as if, during a thunderstorm where the lightning is bad, it strikes the booster before the generators. We have had some cases where they have been burnouts due to lightning through the booster.

Mr. W. S. Taussig, Jun. m.w.s.e.: With normal conditions of service, what is the life of the plates in a storage battery plant?

Mr. Waring: It is largely dependent on the service. I think Mr. Beck can probably answer that question better than I can.

Mr. Beck: Mr. Waring has given me a most difficult question to answer, for the reason that I believe there are no normal conditions. It is very seldom we find two conditions alike, and the result is the life of the battery will vary through wide limits. In a general way I will say that the hardest worked batteries are in the peak railway service. They are worked both winter and summer regularly, two peaks a day, and there are cases where there are three peaks a day, which is the heaviest service we have to meet. Even in this severe service it seems hard to use up the plates in less than four years, and in lighter work their life is naturally longer. You can go up to almost any life. The figures run up to seven and eight years of actual service. In lighter types of railway and of telephone service, the life is sometimes eight and ten years. But in giving the life of storage battery plants we are always at a great disadvantage. Where batteries last eight or ten years, we must remember that they are of the manufacture of eight or ten years ago. Of the batteries made today we have, of course, as yet no data as to life.

Mr. W. D'A. Ryan: The discussion so far appears to center around rather extensive battery systems. I would like to ask a question in regard to the use of the storage battery in department-store lighting. I have in mind a case where they used about 1,000 kw. capacity, and wish to avoid piping the store for gas, but they wish to provide for an emergency. The object of this safe-guard is to prevent a panic in the dark. The proposition is to connect about 10 per cent. of the lights to a storage battery. This battery will furnish light in case the electric plant gives out or in case of fire; the lights will all be extinguished, except those connected to the battery. Furthermore, this battery will be used for lighting at night, the main plant being shut down. I would like to know if this practice has been very generally established.

Mr. Waring: We have put in a number of batteries to act as an emergency reserve for the lighting system. In the case of fire in a department store, such an arrangement might be made; one could figure how long it would take to clear the store. I should think it would be quite feasible to have a battery that would furnish sufficient light for say half an hour in case of an emergency, to get the people out of the building.

Mr. Taussig: A year or two ago some interest was manifested in the electric locomotive which had a gas engine, storage battery, and motors. I would ask Mr. Waring if he can tell us anything about that.

Mr. Waring: We put in on the St. Joseph Valley Traction Co.'s road (about 20 miles in length) a system of that kind, about 2½ years ago. We made a test on that car about a year and a half ago, and it seemed to be giving very good service. The car barn caught fire some three or four months ago and destroyed the car. The owner has now contracted for a larger car, to be operated on the same principle. The results of tests that I have made as to operation were very satisfactory. One thing that rather surprised me was the low power consumption that the car required. The car was pulling a trailer and I think the car averaged only about 40 watt hours generated per ton mile. We carefully checked these figures, which show economical operation. The cost of gasoline for running the equipment was very low. The engine was operated at about three-quarters of its rated capacity, the battery maintaining a very constant load on this unit. The operation of the car was also satisfactory from a purely operating standpoint. The car was in service for three years. There was no expense in connection with the battery in that time, and, as I uderstand it, no expense whatever in connection with the car. However, I do not think that scheme is going to revolutionize railroading. In this particular case the car made only two trips a day, and it would hardly seem a case for a complete generator equipment, over-head line, etc. Another car of that type is the Straug car, that ran from New York to Chicago; the operation of this car was satisfactroy as far as I know.

A COLORADO MOUNTAIN RESERVOIR.

R. M. HOSEA, M. W. S. E.

Presented April 3, 1907.

INTRODUCTORY.

The Sugar Loaf reservoir, owned and operated by The Colorado Fuel & Iron Company, is located about five miles west of Leadville, in Lake park on the Lake Fork of the Arkansas river. It occupies the bed of an ancient lake at the base of Sugar Loaf mountain, a spur of Mt. Massive, one of the principal peaks of the Saguache range, bordering the Arkansas river on the west from Salida to Tennessee Pass. The Tennessee fork and the East fork of the Arkansas river have their rise, respectively, at Tennessee Pass and Fremont Pass, not far from Leadville, and come together in Tennessee park below Leadville, forming with the Lake Fork and other smaller creeks and gulches the main Arkansas river. The park itself is occupied by the main line of the Denver and Rio Grande R. R., Leadville being some 630 ft. higher and upon the western slope of the Mosquito range, bordering the river valley on the east and reached by a spur from the main line. The Denver & Rio Grande R. R. continues north up the Tennessee fork, and crossing the Tennessee Pass, while the Colorado Midland Ry. descends from Leadville, crosses the park and continues west up the Lake fork to the Hagerman Pass. Just below the Sugar Loaf reservoir the Colorado Midland Ry. crosses the Lake fork to the slope of Sugar Loaf mountain, which it skirts, ascending on a maximum grade; the whole length of the reservoir lies below it, forming a most beautiful picture. The mountain slopes are well timbered with second-growth spruce, pine and balsam, and have a grassy flower-covered carpet, on which the winter snows lie until late in the year. The lake elevation is about 10,000 ft. above sea, and in consequence the melting snows do not begin to run off in any considerable volume until June; the drainage area reaches back to the summits of high mountains 14,000 ft. or more in elevation, and on which in the gulches and timbered slopes much of the snow lies all the year through.

The Sugar Loaf reservoir forms part of the system of water supply for the Minnequa Works at Pueblo, which demand large volumes of water in the various processes of steel making. Most of this water is used for cooling purposes, at blast furnaces, and in condensing engines, where it is raised in temperature and then returned to the stream, thus being available for re-use below.

The laws of Colorado provide for the storage of flood waters in reservoirs in times of plenty, which returned to the streams at later periods may be withdrawn at points many miles below in ditches, pipes or conduits, less a fixed discount for loss by evaporation and seepage. The channels of the streams are thus used as carrying conduits, the process being under the direction of the State Engineer and his Water Commissioners, who fix the amount of deduction to be made, from their observations and gaugings of the stream in question. There are numerous examples of such practice in the arid western country, and in one instance waters stored in Twin lakes reservoirs near Leadville are withdrawn from the Arkansas river below Pueblo for sugar beet irrigation, more than 200 miles from the reservoirs. In the case of Sugar Loaf reservoir the water will be in the stream about two days and travel some 130 miles to the lower point of withdrawal.

PURPOSE OF CONSTRUCTION—The main purpose of the construction of the reservoir is to create a reserve supply to insure to the Colorado Fuel & Iron Company the ability to withdraw the amount of water represented by certain water rights, in a conduit tributary to its works at Minnequa. The water rights yield ample supply at all ordinary stages of water in the Arkansas river, but to insure against conditions of extreme low water a stored supply of water, regulating the flow of the river is a valuable adjunct, where interruption in the supply might mean a serious hampering of operations at the works.

HISTORICAL—The Sugar Loaf reservoir was originally selected and surveyed by the U. S. Geological Survey engineers as a Government reservoir site, and certain lands were segregated and withdraw from entry (see the U. S. Geological Survey reports for 1891 and 1892, maps and stream gaugings). About this time also several schemes were proposed whereby the water was to be stored in the lake and conducted in pipe lines or ditches to the site of a power plant in the valley below Leadville, where several hundred feet fall could be secured. There turbine water wheels and dynamos would generate electric current which could be used in Leadville mines for power and lighting. The water would of course be returned to the stream. Considerable preliminary investigation was done on these schemes and some lands acquired at the reservoir site by the parties interested. The Government site was finally abandoned and its lands advertised for sale, under certain requirements of a special Act of Congress, permitting the purchaser to secure title by building a reservoir subject to the conditions of the Act. The matter was finally brought to the attention of the management of the Colorado Fuel & Iron Company, and the writer ordered to report on the project as a part of the proposed water supply for the Minnequa works at Pueblo. This report having been confirmed by an investigation and report of John Birkinbine, Consulting Engineer, it was decided to purchase the interests held by private parties and acquire the Government lands by complying with the Act of Congress. Surveys were immediately begun and prosecuted vigorously, a contract let and material delivered and work begun on construction in 1902. The season was so far advanced, however, that it was impossible to complete the work before winter, as at the altitude (nearly 10,000 feet above sea level) the snows begin in October and frost forms. However, the base of dam was nearly completed and much of the preliminary work done. The work was resumed the following spring as soon as the frost was out of the ground and finished in September, 1903, and in the following winter and spring, water was stored under direction of Prof. L. G. Carpenter, then State Engineer, and the reservoirs nearly filled. This water was withdrawn, or nearly so, the following fall and winter, as some slight seepage had developed beneath the dam (as will be referred to later) in order to give opportunity for settlement and consolidation of the prism of dam and the permeable material below its base. Such alternate raising and lowering of the water level has since been carried out each season.

Preliminary Investigations—This project as originally proposed by the Government engineers provided for a dam to impound a fifty-foot depth of water, which really covers two reservoir sites connected by a narrow neck near the upper end. See Fig. 1. Such a height permitted a spillway to be located only at the south end of the dam and in material not very favorable and on a steep hillside; besides which the dam would require extension on the North end parallel with the Colorado Midland Ry. and above the level of its tracks for some distance, and would present a somewhat formidable appearance to the traveler approaching from below on the railway. The present dam height, impounding 30 feet of water, admits of ample spillway area adjoining the railway and an emergency spillway at the opposite or South end, besides leaving available ground at the railway end of the dam for station or park buildings and resort requirements. See Fig. 1 and 2.

It is thought best to build another dam at the narrow neck referred to should it hereafter be advisable to add to the storage capacity and it be shown that the available supply would justify such addition. The upper lake thus created will impound 20 feet of water and cover a flooded area of some 350 acres, containing 2,500,000,000 gallons.

The photographs, Figs. 3 and 4, show upper and lower sites and the flat character of the park and especially the high mountains in the background, snow covered in July, with timbered slopes and gulches reaching to their summits at some 14,000 ft. elevation.

The average annual rainfall at Leadville is 14 inches, as shown by U. S. Government observations, and the drainage area of the Sugar Loaf reservoir is from 25 to 30 square miles, as determined by the Topographic Atlas sheets of the U. S. Geological Survey.

It is quite probable that observations on the above drainage

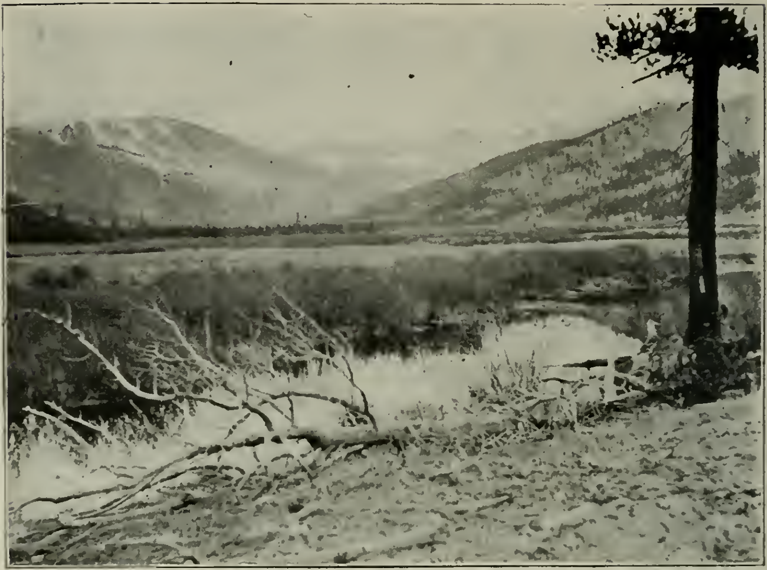


Fig 3—Sugar Loaf Reservoir
UPPER SITE, LOOKING WEST FROM NEAR PROPOSED DAM—SHOWS CHARACTER OF DRAINAGE AREA TRIBUTARY TO RESERVOIR.

Fig. 4—Sugar Loaf Reservoir
VIEW TOWARD LEADVILLE FROM UPPER END OF LOWER RESERVOIR—DAM 1½ MILES DISTANT.

area would show a considerably higher precipitation. Being on the west side of the valley, more and deeper snows fall in winter and more frequent rains occur in summer; this is a matter of local observation.

The run off as determined by the gaugings of the Lake fork shown in U. S. Geological Survey reports, 1891-92, and the gaugings taken by the Colorado Fuel & Iron Company during the two seasons of survey and construction show a discharge in the Lake fork of Arkansas river ample to fill the reservoirs built and proposed, at least once each season. The maximum flow observed is some 600 second feet in June; the minimum 6 second feet in October, continuing until snow begins to melt in the following May.

The storage of water is at all times under the control of the State Engineer and his deputies, who are governed in their action by the stage of water, in the main river and in other tributaries, and they decide as to the amount of storage to be permitted. The summer is of course considered the "irrigation season" and the winter the "storage season," but the latter is affected to some extent by the growing practice of fall and winter irrigation to prepare ground for certain kinds of crops. This shows some of the difficulties encountered in the calculation of rainfall and run-off as yielding a definite storage quantity when planning reservoirs at the heads of running streams like the Arkansas, whose normal flow is greatly over appropriated by water users many miles below.

The advantages of such a site are the elevated timbered drainage area surrounding it, the numerous springs in the drainage area, the water originating on the lands owned, the low evaporation from lakes at such altitude, its shut-in character, etc., all of which contribute to make such a site ideal.

Cloudbursts—so-called—at this altitude and on the slopes of what may be called a secondary range of mountains protected from the direct meeting of mountain and plains air currents, are unlikely, but the location of this reservoir is such that immense damage would be done below it in case the dam were overtopped and carried out. Therefore, extreme figures have been used in providing outlet for the water in the outlet basin, and the spillways at the two ends of dam, as will be apparent in the plans and description of the work following.

Surveys—Surveys of the flooded area, section lines, dam sites, etc., were made and dam located as shown by plans, Figs. 1 and 2. A careful contouring of flooded area for each 5 ft. depth followed and calculation of capacity for each 1 ft. depth by interpolation was made as required by State laws. As all surveys were referred to a base line and the method of latitudes and departures were used, it was possible by using prismoidal formula to get capacities for each foot of depth to within a limit of error of 1 per cent. Test pits at numerous points in the flooded area and at the dam site and a study of the locality disclosed that

(1) The valley was originally closed by a moraine or glacial deposit of clay and bowlders through which the stream had broken;

(2) The reservoir site was an ancient lake bed, underlain wholly or partially by a clay sheet four or more feet thick which extends partially under the proposed dam;

(3) The material in the moraine and on the hillsides and in the vicinity generally was a clay, sand and bowlder mixture, extremely favorable for dam construction.

Borings at the outer or lower half of the dam showed the stream bed here to have an underlying deposit of fine sand of unknown depth and indicated that the clay sheet should not be penetrated by any sheet piling or core wall construction in the body of the dam, but rather favored the making of a juncture with the clay sheet below by a clay lining of sufficient thickness and suitable construction placed upon the inner or water face of the dam.

Surveys and investigations were also made to determine the possibilities of conducting flood waters into the reservoir site from the Tennessee and East forks of the Arkansas river and the areas tributary to them and sufficient data secured to show their feasibility should it be desired hereafter to increase the storage ability. It might be here noted that among the possibilities of this and other storage reservoirs situated on eastern slopes are plans for conducting water over low passes from streams flowing to the Pacific, since as a rule the western slope streams have an excess of water unappropriated. This has in some instances been done already in Colorado.

CONSTRUCTION.

Dam—The first operation was to locate and construct a railway spur from the Colorado Midland Ry. of sufficient length to receive and store material. The contractors, Clough & Anderson of Colorado Springs, having moved onto the work, this was soon done and material was received and unloaded with dispatch, consisting of heavy 48-in. cast iron pipe, cement, lumber, valves, camp supplies and the usual miscellaneous material incident to such a work.

The entire area of the dam site was overgrown with willows and some trees and in the lowest portion, adjoining the stream, covered with one to two feet of black muck. All this had to be removed, roots grubbed out and top or vegetable soil skimmed off. The latter was done by a light plowing and handling with slips. The surface was then benched or furrowed. The channel of the stream was diverted to one side, as indicated on the plan, and excavation made for the pipe cradle or concrete base for the outlet pipes. The north part of dam was built first and extended as far as feasible towards the gap at the South end in the following manner: Adjacent to the Colorado Midland Ry. the spillways were excavated and this material, exclusive of large bowlders, was placed in the

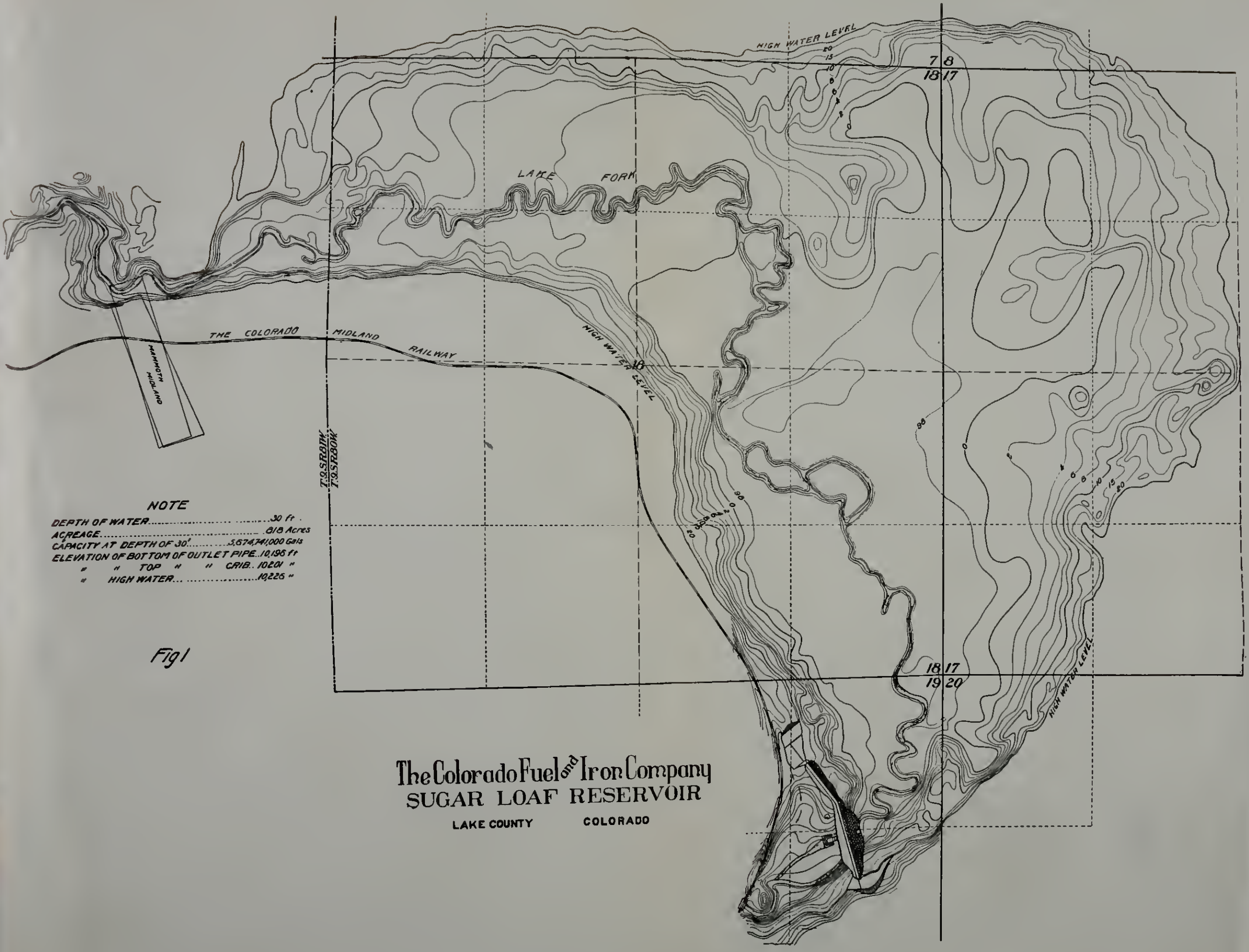

HIGH WATER LEVEL
20
15
10
8
6
4
0
7 | 8
18 | 17
LAKE FORK
THE COLORADO MIDLAND RAILWAY
MAMMOTH MIDLAND
HIGH WATER LEVEL
16
T.9.S.R.81W.
T.9.S.R.80W.
20
15
10
8
6
4
0
99
0
2
4
6
8
10
15
20
18 | 17
19 | 20
HIGH WATER LEVEL
NOTE
DEPTH OF WATER .... 30 ft.
ACREAGE .... 818 Acres
CAPACITY AT DEPTH OF 30' .... 5,674,741,000 Gals
ELEVATION OF BOTTOM OF OUTLET PIPE .. 10,196 ft
" " TOP " " CRIB .. 10201 "
" HIGH WATER .... 10,226 "
The Colorado Fuel and Iron Company
SUGAR LOAF RESERVOIR
LAKE COUNTY COLORADO

Fig 1

Western Society of Engineers.
August, 1907.
Hosea—A Colorado Mountain Reservoir.

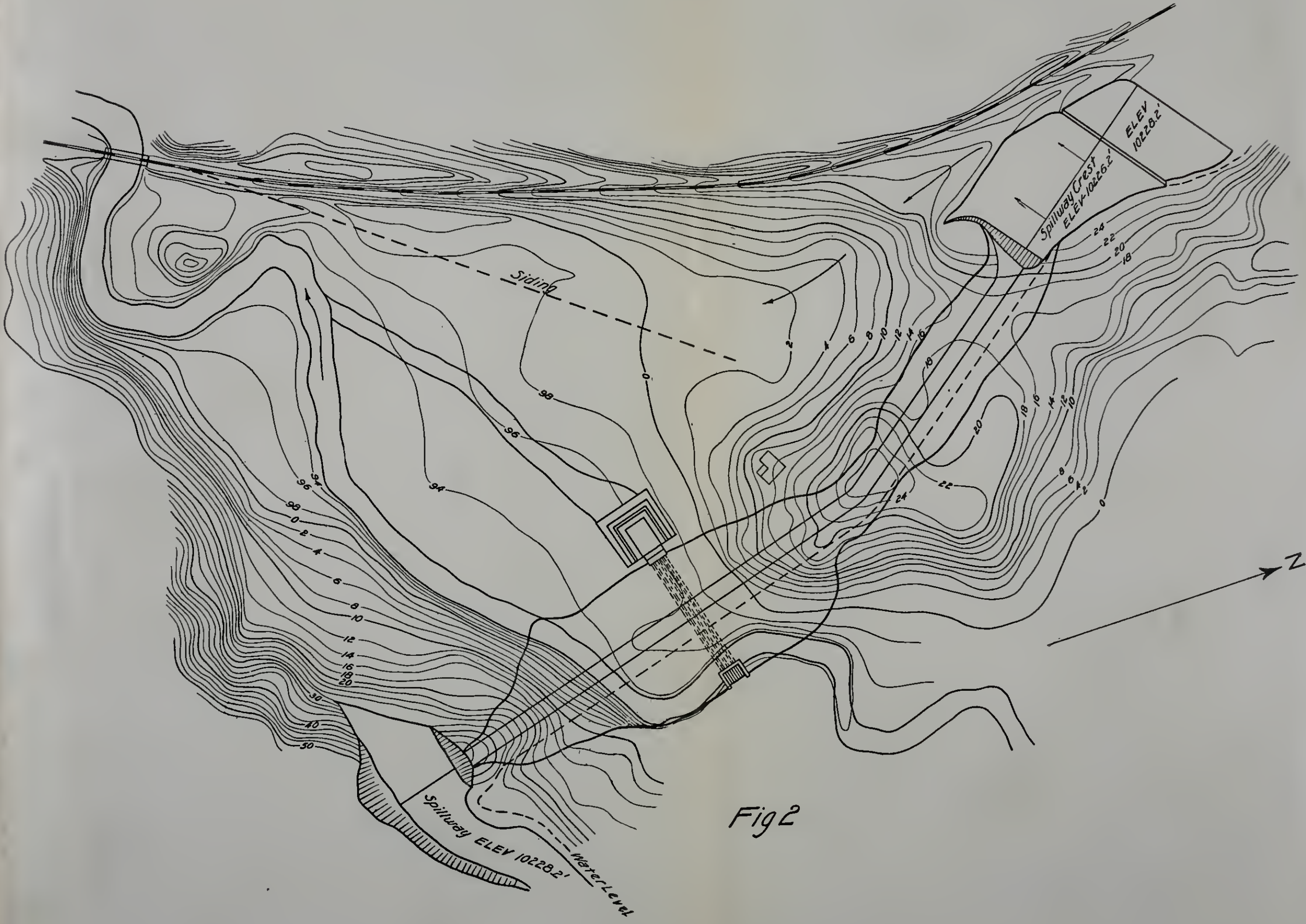


Fig 2

Western Society of Engineers.
August, 1907.
Hosea—A Colorado Mountain Reservoir.

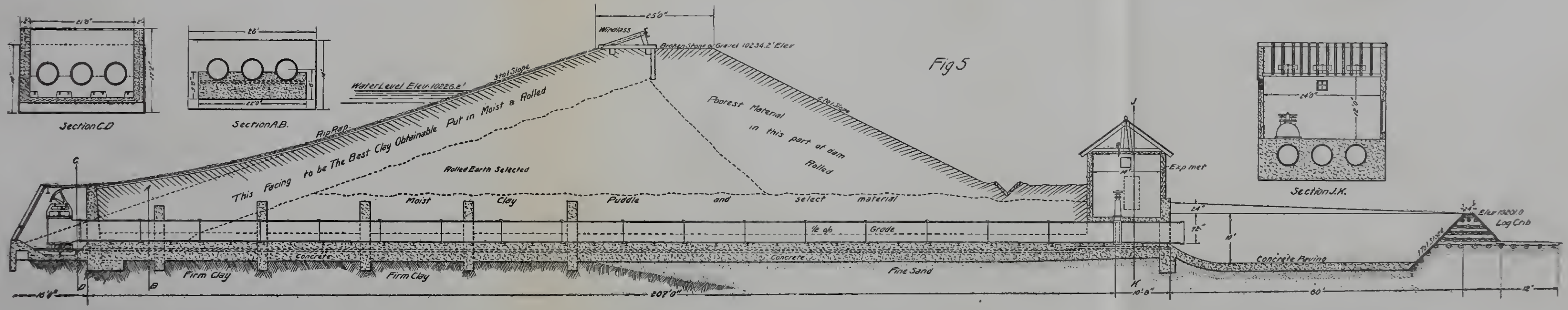


Fig 5

outer part of the dam section. Borrow pits were laid out on the inside of the reservoir site over a large area and stripped of all vegetable matter, exposing the clay-sand mixture (containing some bowlders), and beneath which was the clay sheet four or more feet thick. The dam then was carried up in thin layers by depositing the clay on the inside face to a thickness of 20 feet, then the next best material, and so on to the outside, where the poorest material was used. The whole was smoothed, sprinkled and rolled with a heavy Springfield roller blending all together, the formation of layers being carefully avoided, by depositing loads irregularly.

After the base of the dam was built, it was found best both for economic results and speed to have the contractors install a small steam shovel and load into dump wagons, taking the moraine material from a spur or extension into the flooded area, shown in Fig. 2, which furnished ample material for finally closing the gap in the dam when the low-lying borrow pits were flooded by the raising of the water in the lake. Grading machines were tried for a time, but the presence of bowlders in borrow pits made their use inadvisable, and it was found most economical to load direct from the dipper of the steam shovel into dump wagons, which with a little care was done without undue wear and tear on the wagons. In Fig. 9 is shown the dam partially built, the gap carrying the stream ready to be closed as soon as water can be carried in pipes. Note the flat character of the bottom of reservoir. The cross section plan Fig. 5 shows the manner in which the different materials were blended together to form the dam prism, but it should be stated that the filling in around the pipe and cross walls was done by hand, tamping and puddling with water, and using the best clay material from the borrow pits. This was of a grade that might be termed Potter's clay, very fine and when wetted and worked made a splendid puddle.

PIPE CRADLE—This excavation was first stripped of vegetable matter, roots and muck and the underlying clay sheet exposed to a point about the center of dam, where it thins out into sand of unknown depth; see cross section of dam, Fig. 5.

The trenches for five cut-off or cross walls, about 21 feet apart, were excavated two feet deeper and wider than the balance of excavation, to more effectually check any flow of water along the surface of the concrete. The base consists of 48 inches of concrete composed of the most compact mass that could be made with the sand, gravel and small bowlders existing in the vicinity of the site, determined by experiment for each kind of aggregate used. For part of the work slag from the silver-lead smelters at Leadville was used instead of gravel or broken stone, but was not as satisfactory as the gravel. Both sand and gravel were from granitic formations and excellent in quality, although the sand was rather fine grained. Embedded in the base, 7 lines of 85-lb. steel rails were placed about 3 ft. apart and cross rails 6 ft. apart finished the upper surface, on which three lines of 48 in. dia. extra heavy cast-iron pipe with lead caulked joints were laid, 7 ft. centers, on a grade of ½ per cent. sloping to the outlet basin. The pipes were then bedded between and at the outside in well-tamped concrete to the level of the center of the pipes and the top surface left quite rough and irregular. The cross walls were brought up 4 ft. above the tops of the pipes and projecting 2 ft. beyond the sides of the excavation into the solid ground. After removal of forms, puddling clay was tamped by hand above and around the structure for four or five feet and blended with the next best material as described in the general construction of the dam. Fig. 8 shows pipes and cross-walls ready for filling.

INLET BASIN AND VALVES—At the toe of inner or water face of the dam a concrete basin was constructed, Fig. 5, consisting of a back retaining wall in which the three lines of 48 in. cast-iron pipes were embedded, and two wing or side walls with a concrete bottom. The back wall forms part of the concrete cradle supporting the pipes and extends below it to form a cut-off wall, and in the same manner the front wall and wings are placed well into the clay to cut off any water flow from the 30 ft. head when the reservoir is filled. The front and top of the basin are covered with a screen of iron bars to keep out drift or large fish. The front bars rest on an iron base and interlock and are bolted through with top horizontal bars, the whole resting on a cross I-beam, which is embedded in the concrete side walls at its ends. The bars thus present a smooth surface at front and top from which drift and trash can be readily raked when submerged. Front, side and back walls and the concrete bottom are reinforced with one or more sheets of No. 10 by 3½ in. expanded metal. Supported on 85 lb. rails resting on piers in the bottom of the inlet basin, are three cast-iron balanced valves in T form attached by lead-caulked joints to the bell ends of the 48 in. pipe lines projecting through the back wall as shown in Fig. 6. Each valve has an upper and lower brass lined disc horizontally mounted on a brass bushed shaft; these seat on lead lined brass conical bearings and are operated by a rack and pinion movement to the shaft by means of a sector with grooved rim, carrying a chain which passes between the bars of grating and extends along the slope to the top of dam, as shown in Fig. 6. At this point it is operated by a screw and two-handled nut abutting against a strong wooden frame anchored in the ground; see detail, Fig. 6. The motion of the sector is entirely below the bars of grating and the chain is protected in a trough or groove formed in the riprap face of dam on the 3 to 1 slope which flattens out to meet the top of the back retaining wall of the inlet basin. In this way the valves can be operated without interference from ice or drift or the necessity of a valve tower in the reservoir. The upper and lower discs of these valves are proportioned so that they tend to remain closed at ordinary stages of water, but are normally held open by the chains, the regulation of water outflow being controlled by three Rensselaer geared valves placed at the lower side of the dam next the outlet basin as afterwards described. The cross section of the dam Fig. 5 and the detailed drawings Fig. 6 show these features more clearly. These valves were designed by the Engineering Department of the company from suggestions made by Mr. Gordon Land, an irrigation engineer of large experience in such work. They have been used with success under similar conditions on several other reservoirs constructed under the writer's direction.

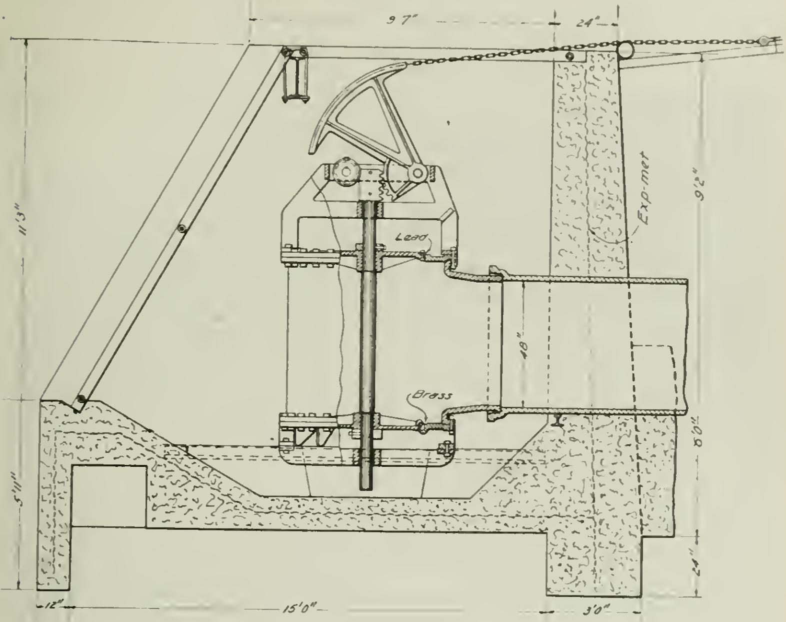


Fig 6

Outlet Basin and Valves—Outside the lower face of the dam, as shown by the sectional view, are placed three Rensselaer geared valves for controlling the outflow. They are enclosed in a concrete valve house with corrugated iron roof built over and resting on the concrete pipe cradle. The walls were built in forms, using one sheet of No. 10 x 3½-in. expanded metal in them, and a cement ceiling was constructed attached to a netting of light expanded metal fastened to the under sides of ceiling joists with 10-d nails or staples. Sixty-penny nails were driven into the sides of joists about a foot apart and the 3-in. ceiling formed around them and between the joists, embedding the netting ½ in. in the under face. A heavy block resting on the joist carrying a ring bolt over each valve and extending through the ceiling serves as an attachment for chain block should it become necessary to take down a valve for repairs. In such an event the purpose of the upper balanced valves becomes apparent to easily shut off the water from any line of pipe. This style of construction of valve house was adopted as being better and cheaper than brick work in that locality and to protect the valves against freezing in the cold weather of this altitude, about 10,000 feet above sea level. Provision is made also for setting a stove, and banking around valves with saw dust, etc., if necessary in extreme cases. To further guard against frost the outlet basin is constructed as shown by the drawing, with a concrete lined bottom and three sides of log cribbing filled with rock and sand and double boarded with Burnettized plank, with a caulked oakum joint where it abuts against the end wall of the pipe cradle. This construction maintains a water cover of two feet over ends of outlet pipes at all times and prevents frost from entering the ends of pipes and reaching the valves. The basin serves also to retain the fish and to spread the outflow of water into a thin sheet falling over the three sides of the basin to the apron outside; thence it can run quietly to the stream below.

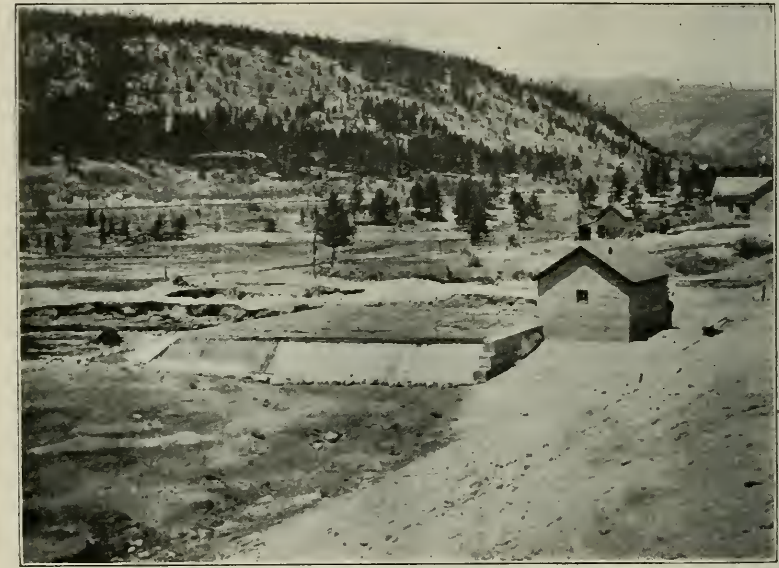


Fig. 7—Sugar Loaf Reservoir

LOOKING NORTH FROM DAM AND SHOWING OUTLET BASIN, VALVE HOUSE AND GATE KEEPER'S HOUSE.

The photograph, Fig. 7, shows the completed outlet basin and valve house looking west from the dam, the Colorado Midland Ry. and Sugar Loaf mountain in the background.

Gate-Keeper's House—A four-room dwelling house was built, with concrete cellar and foundation walls, on the slope of the morraine just below the dam and about 10 feet below high water elevation in the reservoir. The house has a frame of studding covered outside with a 2 in. cement coating on light expanded metal and the inside is plastered with cement plaster on wire lath, the whole making a warm, dry house. As this morraine forms the base of the dam, is several hundred feet thick and is composed of clay material no danger is anticipated, although there has been some slight seepage below the level of the house, which is attributed to breaking through of the inside clay bottom by the steam shovel borrow pits at the inner edge of the morraine, and exposing a thin sand stratum. This seepage has nearly ceased and will disappear as further consolidation of the base occurs and there is some deposition of sediment in the reservoir.

Rip Rap—The bowlders from spillway and borrow pit excavation and from the slopes of the adjoining hills were hauled to the dam and the rip rap facing or paving carried along concurrently with the progress of the dam. The amount and quality of this work is of prime importance at this locality, as there is a long exposure, about 1½ miles, for wave formation and the formation of ice on a full reservoir in winter is considerable. Owing to the sheltered locality, however, and the direction of prevailing winds the wave action is not so great as might be expected. The ice forms some times over 36 inches thick, but usually melts quietly and thus far shows little tendency to dislodge the paving.

The rip rap is laid in three zones, a lower one resting on a base at toe of slope with maximum and minimum thickness of 15 in. and 10 in., a middle zone with maximum 12 in. and minimum 8 in. extending to the flow line, and an upper zone with maximum 6 in. and minimum 4 in. thickness to top of dam. These merely indicate the quantities that were paid for, as the material composing the rip rap is glacial bowlders and fragments of broken bowlders and the actual thickness as laid is greater. The bowlders were laid to a fairly smooth top surface supported on smaller stones where necessary and chinked with spalls, with the sides running the long way of the dam and ends breaking joints on the slope.

Spillways—The contour plan of dam location, Fig. 2, shows the spillways at northerly and southerly ends of dam, also the pipe outlets and outlet or overflow basin and the final return of the water into the original stream channel below the dam. The railway crosses Lake creek with a 64 ft. Howe truss span, having 6 ft. or 7 ft. headway below, but the actual channel is much less. Below this point the stream has a very rapid fall. The greatest known flow of the river is about 600 sec. ft. during the season of melting

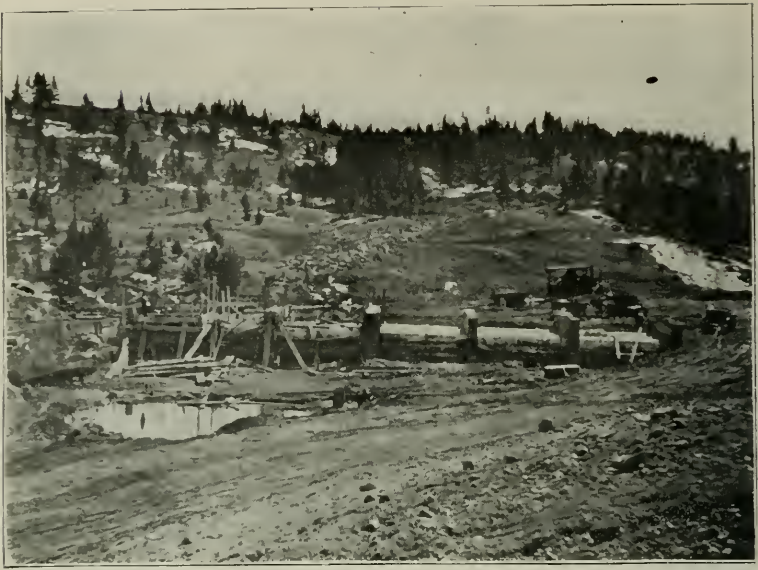


FIG. 8—SUGAR LOAF RESERVOIR
DAM SITE STRIPPED, OUTLET PIPES, CRADLE AND CROSS WALLS UNDER CONSTRUCTION—FROM SOUTH END OF DAM, JUNE, 1903

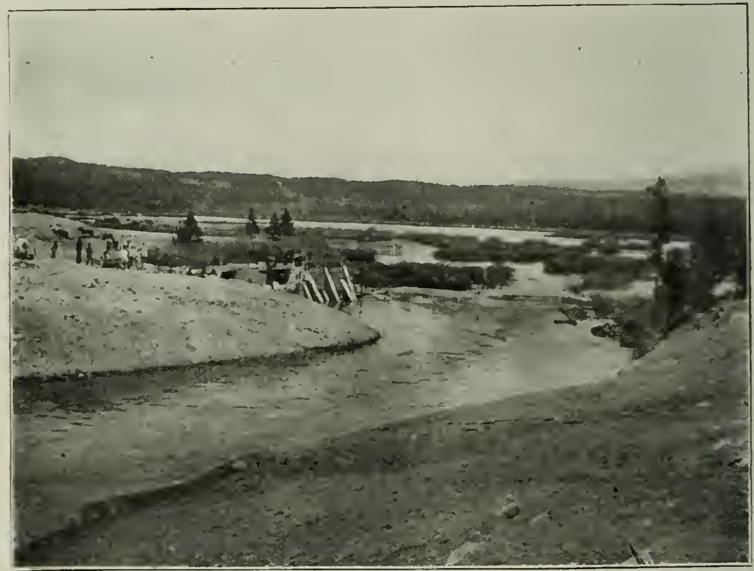


FIG. 9—SUGAR LOAF RESERVOIR
DAM UNDER CONSTRUCTION—STREAM FLOWING THROUGH GAP IN DAM, 300 CUBIC FEET PER SECOND, JUNE, 1903.

snow. Any theoretic length of spillway based on these facts or on an assumed rainfall and run-off would give much less capacity than that here shown. It does not seem worth while to discuss the theoretic requirements except to state that they guide us to a minimum which in this case has been exceeded and as much spillway capacity provided as a reasonable cost permitted. As the excavation for these was all used in the dam the cost was purely nominal. At the north end of the dam a favorable spot exists in ground composed of clay and bowlders, where a level crest excavation 200 ft. long was made at high water level, elevation 10,226. Below the crest, a 1 per cent grade to the surface, slopes into a natural hollow discharging below the dam. This part of the site is well grown with trees and willows which with a rock strewn surface furnish ample protection from scour. To the north of and adjoining the 200 ft. an additional 100 ft. was excavated at a level 2 ft. higher, or 10,228. At the south end of the dam an excavation 100 ft. wide at the same upper elevation was also made.

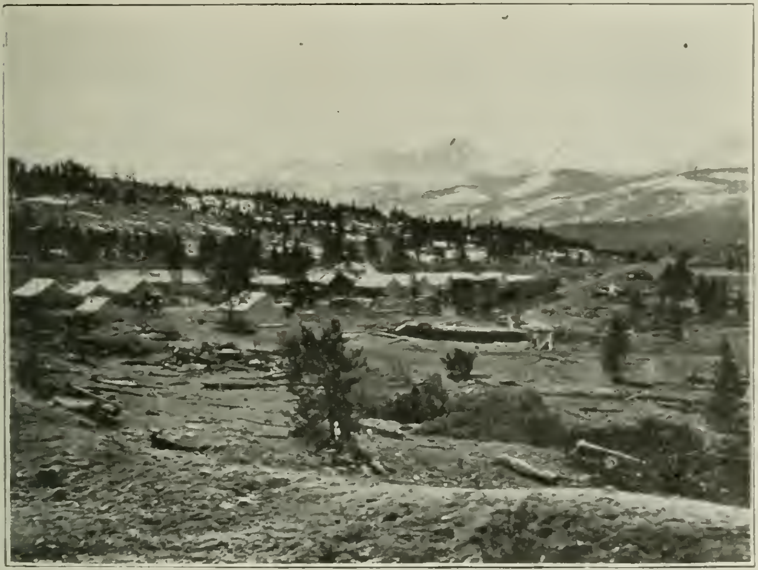


FIG. 10—SUGAR LOAF RESERVOIR
LOOKING DOWN VALLEY OF LAKE CREEK FROM DAM—CONTRACTOR'S CAMP AND SPILLWAY DISCHARGE—MTS. MASSIVE AND ELBERT IN DISTANCE.

The three lines of 48 in. pipe are each capable of carrying 400 cubic feet per second when the reservoir is full, and the flooded area is 818 acres at 30-ft. depth. The top of dam is 8 feet above high water line. From this it is seen that the three lines of pipe alone more than suffice to carry any ordinary flow, as the usual spring melting of snows produces about 350 to 400 cubic feet per second and at such time the reservoir is being filled. Should the water from any cause rise 2 feet above high water mark the spillway could then carry a sectional area of 400 square feet, and an additional 2 feet would add 800 square feet to this or 1,200 square feet in all, making a discharge capacity added to the pipes aggregating in all over 7,000 cubic feet per second, or more than ten times the greatest known flood, and this level would still be 4 feet below the top of dam. Such a discharge would wash out all bridges below the dam. Owing to the immense damage that would be done by overtopping the dam and its destruction of railway lines and other works below, these precautions have been taken which may seem extravagant. Fig. 10 shows spillway discharge, character and rapid fall of country below dam.

The Flooded Area—The flooded area of lower site, Figs. 1, and 4, contained considerable brush, dead and burned timber and some live trees. All the logs and brush were gathered into piles and burned during the progress of the work. The live timber or such as was needed was used in construction of outlet cribs at dam. The bottom land flooded was covered with black soil which made the water somewhat black and offensive the first season of flooding, but it has now cleared up and the water is of a deep blue, clear color, justifying the name of Turquoise lake that has been given the reservoir by the railroad people who have advertised it as a resort.

Engineering Features—The following features of the dam may be worth recording:

Total quantity earth from borrow pits was,		96,762 cu. yds.
Total quantity earth from spillways was		17,601 cu. yds.
Total Excavation ……………………		114,363 cu. yds.
Top soil wasted,	17,475 cu. yds.	
Rip rap stone from excavation,	1,500 cu. yds.	18,975 cu. yds.
Actual excavation put into dam,		95,388 cu. yds.
Actual cross section of dam,		90,200 cu. yds.
Difference,		5,188 cu. yds.

Shrinkage, $5188/95388 = 5.44\%$.

It should be noted that the dam remained partly completed through one winter and had a chance to become compacted, although it was thoroughly sprinkled and rolled during all the construction before and after this interval.

The estimated cost of the dam, including the site, lands, materials, labor and engineering was $127,655.00, and the final cost was slightly within this amount.

The contractors were Clough & Anderson, of Colorado Springs, Colo., who took a great personal interest in and did an excellent piece of work, reflecting credit on them.

The work was done under the direction of the writer as Chief Engineer; W. M. Porter, Assistant Chief Engineer; W. D. Salter, Resident Engineer, of the Engineering Department of The C. F. & I. Co., and Jno. Birkinbine, Philadelphia, Consulting Engineer; all plans and construction having been approved by the then State Engineer, A. J. McCune and his successor in office, Prof. L. G. Carpenter.

DISCUSSION.

Mr. C. B. Burdick, M.W.S.E.: The Society is indebted to the author for a very interesting paper upon a subject that comes up frequently in hydraulic construction. This type of dam is probably more used than any other. There is no better, more economical or more enduring type than the earthern dam similiar to that described, in situations where its use may be permitted, and there is scarcely a case in hydraulic construction where it may not be properly used in some part of the work. The engineering profession is indebted to the engineers of the far west for some very interesting examples in construction of this kind, which depart, in some measure, from the old and established practices of this form of construction.

These designs cover some interesting departures from former practice in the construction of earthern dams, and the inception and development of the rock fill type, particularly applicable to some western reservoir sites. In several instances there has been noted the tendency to cut down conservative safety factors. I would say, however, that the cross section of the dam described would be considered a conservative cross section anywhere. The absence of core wall is notable. It has commonly been considered necessary to structures of this type, particularly in the east. It is less applied in the west, and I believe there are many cases where it is not necessary. It is quite possible that the case cited here is one of them.

Upon a recent trip to the coast I had the pleasure of seeing some earthwork constructed in rather a novel manner. This was at Seattle, where they are filling the tide flats by the hydraulic method similiar to that employed in placer mining. A great hill is being cut down and the material transported more than half a mile in wooden pipes. This style of construction has been used with success on a number of western railroads in making deep fills, and a number of earthern dams have been built by this sluicing process. I rather wonder that this method was not tried upon this construction. They apparently have considerable clay at a good elevation.

Mr. J. H. Warder, M.W.S.E.: Would you not regard that inner lining of the dam of clay as an equivalent to a clay core wall?

Mr. Andrews Allen, M.W.S.E.: One would expect to find a core wall *in the core* and not on the side.

Mr. Burdick: I think western engineers would contend that the water face of the dam was the very best place for a core wall.

Mr. Allen: I would ask how the spillways are faced,—if they are paved like the other portion of the dam, or if they have a concrete facing?

Mr. Burdick: In a dam that we constructed this last year we paved the spillway with concrete. We built a wide spillway, having a steep slope, and concentered it into a channel. The case spoken of in the paper is a very unusual one. The author speaks of the maximum flow as 600 second feet in June, and of the capacity of each of those pipes as 400 cubic feet per second, so he has some reserve in his outlet pipes, in passing the largest measured flood, and it is probable that if the flood ever over-topped those spillways, it would be only of short duration, and probably not injure the construction.

Furthermore, the spillways appear to be all in natural bank, and cutting is slow in a natural hard-pan bank of that kind.

I was somewhat interested in the controlling valve shown. The balanced valve upon the inside of the reservoir is somewhat novel. I do not quite understand, however, how it is expected to work that chain when the reservoir is covered with ice. Upon a recent piece of work we had a similar problem. We wished to avoid the construction of a valve tower in the reservoir, and placed an elbow at the up-stream end of the pipe, and connected thereto an ordinary waterworks valve. The valve is laid on an angle of 45 degrees, pointing up the bank and is operated by a long valve stem enclosed in a pipe all embedded in the embankment below frost. The valve chamber is situated at the top of the embankment.

Mr. W. B. Storey, M.W.S.E.: There is one point in the paper that I might call attention to, which seems new; that is, the shrinkage mentioned. The author shows that the material taken from the borrow pits and spillway occupied 5 per cent. less space than in the original ground. I would like to know if anyone has heard of any such grade shrinkage as that, or has run across that fact before?

Apparently the character of the material was against building the dam by the sluicing process. In order to make a success of building the dam by water, the material must have a certain amount of sand in it, and it must disintegrate to a certain extent. Clay as a rule (especially when it is as pure as indicated in this paper) tends to ball up and does not make a good, watertight dam.

Mr. Burdick: In regard to that I would say that at Seattle they are using practically a brick clay, and this is also true at Danville, Illinois. I have some photographs taken from the bank at Seattle that look like rock. There is a brick plant on the hill where the excavation is being taken out. It is true the clay does not sluice as easily as some other material, but they are able to transport that material at good profit and carry it half a mile.

Mr. Storey: There is no objection to moving material by sluicing, of course. The point I was trying to make was relative to compacting the material and making a waterproof dam. I think probably the principal reason that this process would not be used in this particular place where they were trying to make a layer continuous with the layer under the dam is that deposit would be in the shape of balls. Possibly at Seattle it was being placed in mass and for the filling in of land. The railroad filling in the northwest has almost always been where there is gravel. Handling clay by this method is rather expensive. In hydraulic mining the way in which the bank is attacked is by undermining with the hydraulic monitor, allowing large masses of clay to cave down, and carrying them through the sluices. But material so carried will not make a first class dam.

Mr. John Birkinbine (by letter): The problems to be met by the engineer who seeks to utilize the precipitation upon, or the run-off from the mountains forming the continental divide of the United States, and a considerable area on either side of it, are quite different from those to be carried out in the section of the country where rainfall is more copious or evenly distributed. The writer's familiarity with the hydrological conditions in the Rocky Mountain Region, in what may be considered the arid or semi-arid sections, has impressed him with the resourcefulness of local engineers who meet conditions and overcome difficulties in a masterly manner.

As consulting engineer for the Colorado Fuel & Iron Co., for the past 8 years, the details of the water supply for the growing works of this corporation demanded a great deal of attention, and the relative merits of pumping and gravitation supplies, of condensing steam, of recooling water, all received thorough investigation. The territory which was convenient to Pueblo, the site of the company's works, was investigated, and hundreds of miles of wagon travel was necessary to accomplish this. Several hundred miles of survey was run before the present project was decided upon, and during construction, corps of engineers with instruments made many miles more of surveys.

The scheme as outlined by Mr. Hosea will undoubtedly impress the reader as very pretentious, for an individual steel plant to maintain a line of conduit 42 miles in length, in addition to large receiving reservoirs and an impounding reservoir 160 miles up the Arkansas river, and the natural question will be "does it pay to spend so much money for a water supply?" The reply to these criticisms is that the works established were growing rapidly, and promise to continue to grow; that for any large steel producing plant, water in large volume is essential, and that barring accident to the line of conduit, the expense for interest and maintenance, divided by the daily capacity of the conduit, will not make the water supply for the Minnequa plant cost more per million gallons, than that furnished to some other steel industries by pumping from streams.

The impounding of water in large reservoirs, such as the Sugar

Loaf storage, described by Mr. Hosea, demands a study of the varying conditions of snow on the mountains, the time of its deposition, whether early or late in the season, the effect of winds driving snow into canons and gulches, the packing of this snow, and the alternate thawing and melting which give an icy surface, all influence the amount of run-off and the time during which the water passes down the streams, and consequently the excess water which can be impounded.

The storage of water in reservoirs on the plains where there is an underlying, pervious strata, reached through the abandoned homes of burrowing animals, closed by sand and unnoticed until reopened by wasting water, the evaporation due to abundance of sunshine, prevailing winds and a dry atmosphere, all demanded attention; and in the utilization of water at the steel works altitude had to be considered as affecting the generation of steam, natural draught and the oxygen furnished by the air which passed through the blowing engine.

In constuction, provision was made for what are properly termed "cloud bursts," where stream beds, dry for most of the year, are transformed in a short time into rushing torrents by the heavy downpours on limited local areas wich prevail along the frontal range.

Mr. Hosea has instructively explained the work done which is necessarily the sequel to patient and painstaking investigation.

CLOSURE.

Mr. Hosea: It was a source of great regret to the author that he was not able to be present in person at the Society meeting to take part in the discussion.

Mr. Burdick suggests that a cross section of the dam would be considered conservative anywhere and that the absence of core wall is notable. I think it is sufficiently plain for reasons given in the main paper why a conservative section was chosen, and some of the reasons are given why the clay facing was chosen in preference to penetrating the underlying clay sheet with a core wall. As a matter of fact, all the material used in the dam section would be considered good dam-making material and suitable for the purpose, without either core wall or facing.

Mr. Burdick speaks of the so-called hydraulic method of dam making and wonders that it is not tried here. The character of the material was not considered suitable for this method nor was the water available to carry on this kind of work. It is doubtful whether the preliminary expense of getting the water under pressure to the proposed borrow pits and conveying the material to the dam would be justified for a dam of this size; besides which the water rights in this country are jealously guarded and it is not feasible to use them except for irrigation purposes. In the present instances, all the water that is stored in the reservoir is stored in the winter and early spring before irrigation begins.

In regard to the operation of the balance valves. The areas are so calculated that there is not any severe closing pressure even when the reservoir is full. They are intended to be and remain open except in emergency. If the reservoir were covered with ice and it was desired to close the valves, there should be no difficulty in freeing the chains from the ice for the purpose of closing them.

Mr. Allen speaks of facing the spillways. The spillways are not faced, but being cut in natural ground, which happens to be largely boulders, it is not considered that cutting is likely to occur. With the reservoir full the outflow will be regulated by the valves. We are not dealing with cloudburst floods at the period of maximum flow, but with melting snows, which can be much more easily handled. As a measure of prudence, however, and since this paper was prepared the paving of the spillways has been in progress. Owing to accident or mischief the chains connecting two of the valves to top of dam became inoperative. It became necessary to have a diving outfit recover them before they could be operated. In the meantime some water ran through spillway and occasioned alarm. We decided to pave and thoroughly protect a spillway area of 200 feet in width, so it could carry at least the maximum flow of 600 second feet with entire safety. This has now been done and further precaution will be taken to guard against anything happening to the valves to prevent them from being operative at all times; in other words, making them "fool-proof" if possible.

THE WORK OF THE SANITARY DISTRICT OF CHICAGO; THAT ALREADY ACCOMPLISHED AND YET CONTEMPLATED BELOW THE CONTROLLING WORKS AT LOCKPORT.

By Isham Randolph, M.W.S.E.

Presented June 26, 1907.

It is now nearly twelve years since I addressed this Society about the things we were doing and the things we were going to do,—twelve long years—and in that time we have wrought a wonderful change. The Chicago River flowing to the southwest and the waters of Lake Michigan are being delivered moment by moment into the Gulf of Mexico; the back bone of the "divide" has been cut through and the way is now open for a great ship canal from Chicago to the Gulf.

The subject of water transportation is one of the most pressing questions now before the American people. When such great men in the railroad world, as Mr. James J. Hill admits that the railroads are now unable to do the business of the country, and that the waterways must be called in as auxiliaries, we can appreciate that the time has come for our Government to improve the internal waterways. But the subject of waterways is not for this address, but rather to tell of some of the things that the Sanitary District is doing and of the things it proposes to do. In looking back over the work done, while it is a personal pleasure to speak of that work it is a still greater pleasure to talk about the men who have made possible the results obtained. For fourteen years I have been in charge of this great work;—fourteen years of toil, anxiety and of measured success; but that measure of success has been made possible, by the ability and loyalty of the men who helped in this work. It is a pleasure to think of the loyalty of these men, and to hope that they may all attain that success in life which their talents and loyalty deserve.

Many years ago, when I first took hold of the work of the Sanitary District, I went to it from a life of railroad engineering, and with but little knowledge of hydraulic work. I made known this fact to the Sanitary Trustees, but it was their pleasure that I should assume charge of the work. After I had been in charge but a short time I realized that there would eventually be a great flood flowing down the channel that was to be built, and this stream had a potentiality, the conservation of which meant an immense resource to the Sanitary District, in the way of water power. On my first vacation I went to Niagara Falls and spent two or three days there with the hydraulic and electrical engineers in studying what was being

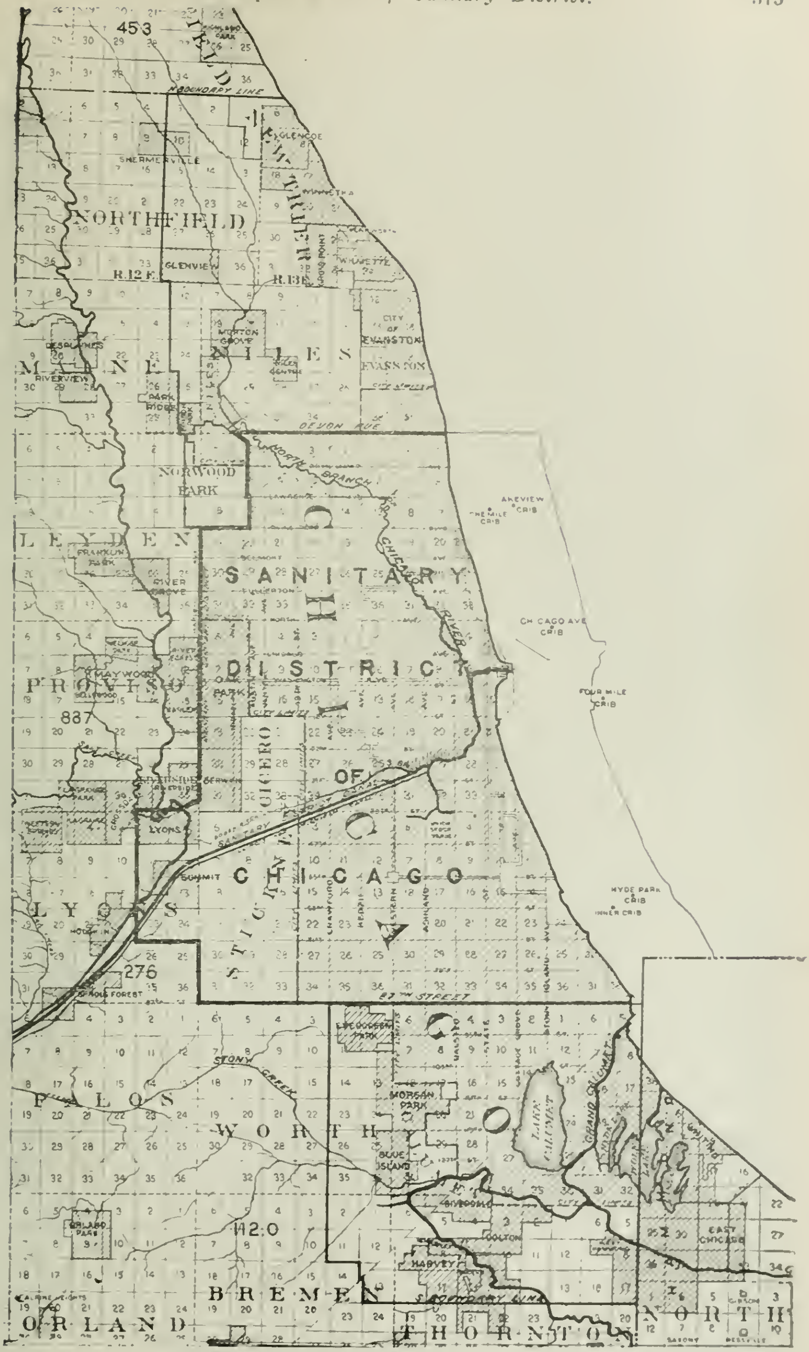


Fig. 1.—The Sanitary District of Chicago.

done in the utilization of their water power. On my return I made a report upon the great possibilities of our water power. The time is now measured by months, I might almost say by weeks, when this dream of nearly fourteen years ago, and which has been taking shape since then, will become a realization; when the waters of Lake Michigan, carrying away the sewage of Chicago, will pass through the new water-power plant near Lockport and develop a tremendous electric power.

Referring to the map, Fig. 1, is shown the Sanitary District of today. The original limits of the District were from 87th Street on the south, to Devon Avenue on the north. In 1903 a law was passed which added to this territory about 74 sq. miles on the north (known as the North Shore District) and about 92 sq. miles on the south (known as the Calumet District): the total area of the Sanitary District today is 358 sq. miles.

The location of the origianl Sanitary Canal is well known to most of you,—passing down from the Chicago River near Robey Street and down the Des Plaines Valley to Lockport, where the water was discharged into the Des Plaines River.

The plans now under consideration and which will be carried forward as rapidly as our limitations permit, are:

First; on the North Side a canal extending from Wilmette, southerly along the western limits of the City of Chicago and joining the north branch of the Chicago River at Lawrence Avenue. To obtain a flow in this canal, to dispose of the sewage of that part of the district, pumping will be necessary. The pumping works will be at the north end of this canal and will be of a capacity of 60,000 cu. ft. of water per min. When this work is completed and in operation, and also the Lawrence Avenue Pumping Plant, all the sewage on the North Side, as far as Wilmette, will pass down that canal and the north branch of the Chicago River.

On the South Side, in the Calumet District, the conditions are different. There it is proposed to reverse the flow of the Calumet River (as the flow of the Chicago River was reversed) carrying it down through the Sag Valley and discharging the water and sewage into the main channel opposite Sag Bridge (now called Lambert) on the "Alton" railway. But this work is now held in abeyance.

The International Waterways Commission, consisting of three American and of three Canadian members, has reported to their respective Governments, recommending that the amount of water to be taken from Lake Michigan by the works of the Sanitary District be limited to that volume, which is intended to be taken through the main channel, viz. 10,000 cu. ft. per sec., though we asked for an additional flow of 4,000 cu. ft., a total of 14,000 cu. ft. per sec. When we built the main channel we did not go to Congress for a permit to turn the river into it, as we had faith that our work would be acknowledged as the right thing and that when the proper of the

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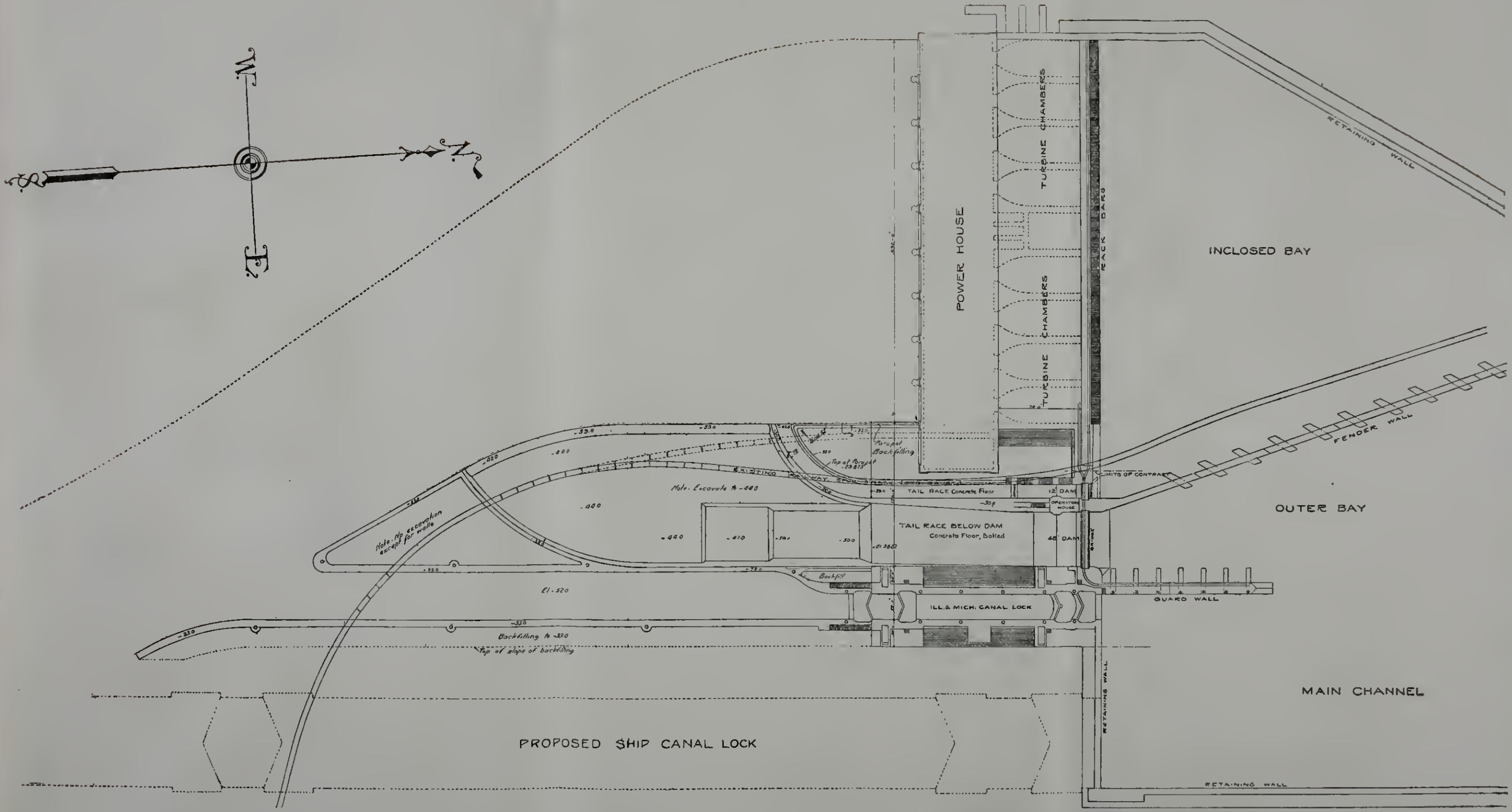
Western Society of Engineers.
August, 1907.
Randolph—Work of Sanitary District.



time came, a permit would be given to reverse the flow of the Chicago River.

Just before the time of opening the main channel an appeal was made to the Secretary of War for that permit and it was granted, nor has Congress ever seen it necessary to revoke it.

Knowing that opposition existed against the improvement of the Calumet River, we consider it advisable to go to the Secretary of War in advance and ask for a permit to reverse its flow. This question was argued on two occasions before the Secretary of War, and the advice of the Attorney General was asked on this subject. The Attorney General advised the Secretary of War that he could not issue a permit on an improvement of this kind without the concurrence of the Chief of Engineers. The Chief of Engineers refused to concur, so the permit could not be issued.

On the 4th of May, last, the President of the Sanitary District brought this question before the Secretary of War for further argument and our Attorney presented his arguments so forcibly that the Secretary of War said a test case would be made of it, and the case carried to the Supreme Court, that the rights of the Sanitary District be settled, once for all.

To consider now the utilization of this water power, and also to provide for navigation, it was considered the best plan to extend the channel of the Drainage Canal in a southerly direction about two miles, that a greater head might be secured for the water power.

At the controlling works, as you may remember, there are the Bear Trap dam and the seven "Stony" sluice gates for regulating the flow in the canal. The top of the wall surrounding the basin at this point has an elevation of +5 (five feet above Chicago Datum), and the bottom of the channel has an elevation of —30.1 (below Chicago Datum). The general ground level here is about —12, and falls rapidly down the valley, so that in the next 10,000 ft. the level is in the neighborhood of —36. The plan decided upon extended the channel down stream 10,700 ft. to a point when a fall of 34 ft. could be had.

The East Side of this channel is a concrete wall of a uniform height of + 5 (Chicago Datum) and backed with broken rock and earth, so the entire width of wall and enbankment is 50 feet. The channel has a greater width than necessary for the passage of boats and includes a considerable portion of the Des Plaines River, that a volume of water would be had sufficient to avoid great oscillations in the water level at the power house when passing boats through the lock. The west boundary of this pool is part embankment, having a heavy clay core for about three quarters of a mile; the enbankment is faced with broken rock on both sides. Commencing about 600 ft. north of the "Wire Mills Road" a concrete core wall is built, extending down stream to within about 1,400 ft. of the power house.

This core wall is about 3 ft. wide on top and 7 ft. wide at bottom, and the top of the wall has an elevation of —10. It is buried in clay and this again is buried in broken stone.

This wall and the enbankment (under construction) is shown in Fig. 2. The clay was hauled from the spoil banks of the Drainage Canal, section L. and M., about 24 miles distant. To provide facilities for handling this clay, amounting to over 325,000 cu. yds., a track was laid over this core wall being supported on the channel

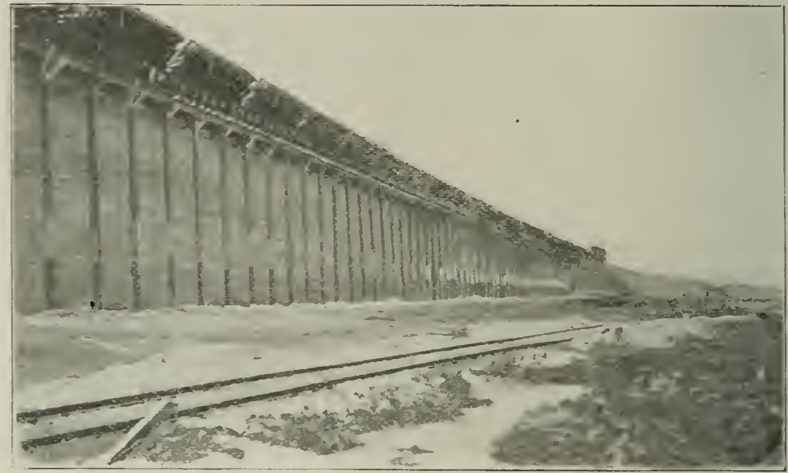


Fig. 2.—Concrete Core Wall.

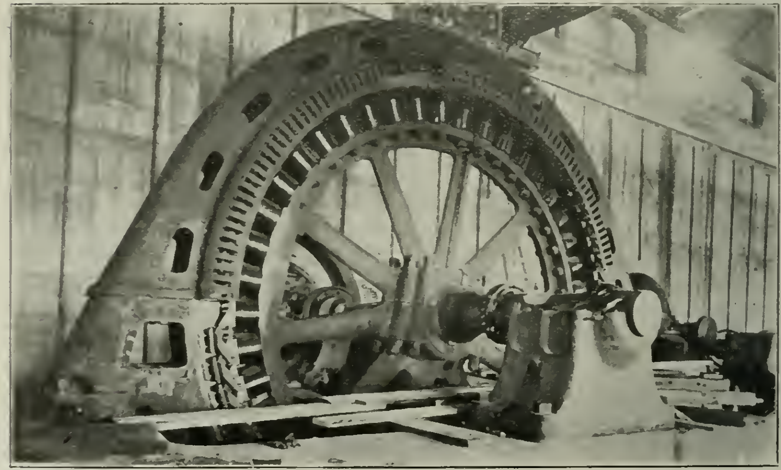


Fig. 4.—A Large Alternator.

side by posts, as shown in the illustration, the other end of the caps resting on the concrete core wall. Dump cars as shown, handled the clay, delivering it on either side of the wall. The clay was puddled with a water jet, which proved to be an admirable method of compacting the clay and with excellent results. In Fig. 3 is shown the end of this pool, the location of the power house with its turbine chambers, the location of the lock and movable dams, etc.

The Power House is 386 feet long and 69 feet wide, with space

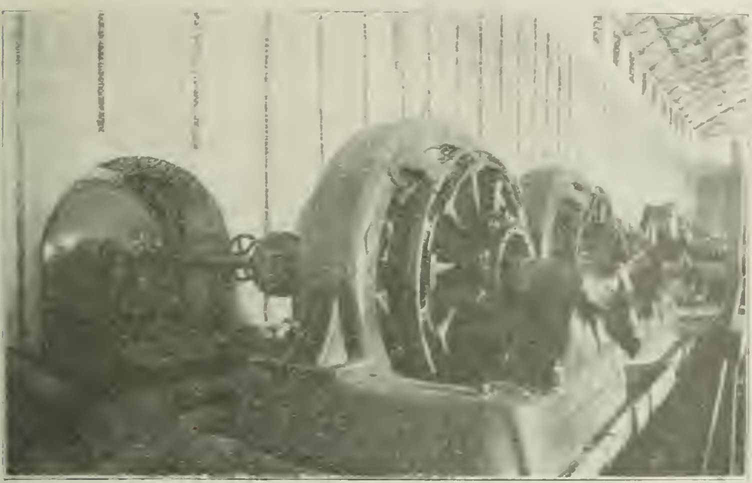


Fig. 5.—The Exciter Units.

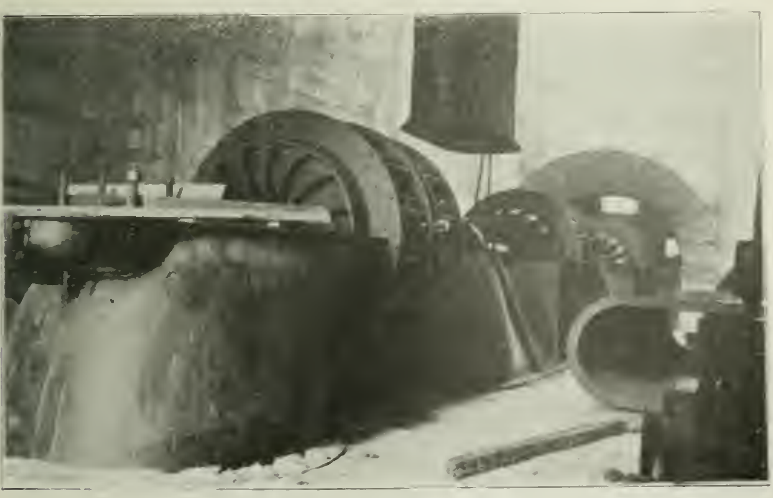


Fig. 6.—Three Pair of Turbines, under construction

for 8 large a. c. electric generators, and also the space for the three exciter units. The large alternator is shown in Fig. 4 and two of the exciter units in Fig. 5. Adjacent and part of the Power House are the nine turbine chambers 65 feet long, and in which are installed the three pair of horizontal turbines, as shown in Fig. 6 under erection, and in Fig. 7 as completed. Each pair of wheels is on its own section of shaft, 12 in. diam., the sections being of three different grades of steel. The shaft is guaranteed to transmit 6,500 H. P. The water enters the wheels at the periphery and is discharged from the center through curved cast iron connecting tubes to the draft tubes below the wheels, which are worked out of the solid concrete masonry foundation of the water-wheels. These draft tubes, which are of peculiar construction, and we believe of great merit, were designed by Mr. L. E. Cooley.

The head of water at the turbines will ordinarily be 34 ft. The turbine shaft will run in oil bearings, the oil being piped under pressure to them and then flows to a receiver to be used again. To give access to the bearings for inspection, etc., water-tight inspection tubes are installed, shown in the views of the turbines. These tubes extend up above the water level of the turbine chambers so they may be readily entered by attendants at the plant. The regulation of the turbines is effected by Lombard-Replogle mechanical governors. The contractors for the water wheels were Wellman-Seaver-Morgan Co., of Cleveland, Ohio, and the work is a credit to them. The eight electric generator sets (alternators) Fig. 4 of 4,000 k. w. capacity are 29 ft. diam., run at 163 rev. per min., have 44 poles and give 6,600 volts 60 cycle, three phase current. The three exciter units, shown in Fig. 5, are 600 H. P. each, two of

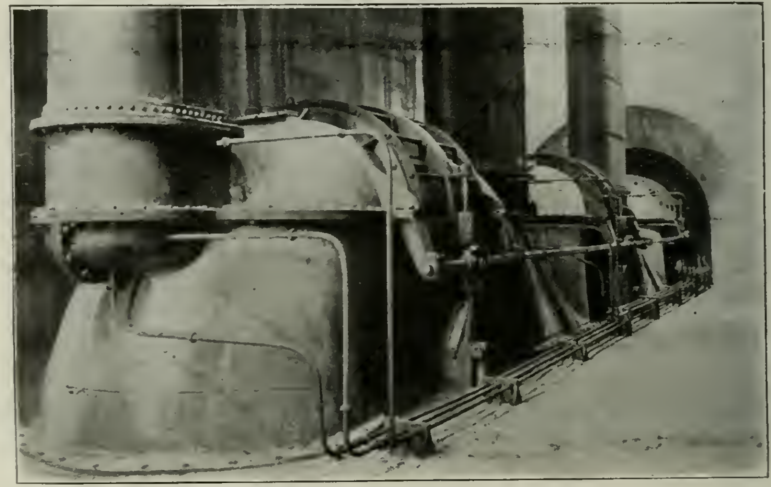


Fig. 7.—One set of Turbines, installed.

which have been installed. All this electrical machinery was built by the Crocker-Wheeler Electric Co.

A view of the Power House, showing the 9 arched openings for the discharge of the water from the turbines, is shown in Fig. 8. The House is built of concrete blocks of a T shape, which interlock and enclose an air space that should make a dry wall. The blocks were treated with a water-proof compound, but after exposure to the weather over last winter, the water-proofing had disappeared. The Power House was designed by Mr. Barrett, who was originally in our bridge department, and who I think has done himself great credit in the design.

Referring now to Fig. 9 there is shown the Ice Fender wall with the submerged arches, which admit the water to the fore-bay. Over the wall and beyond the fore-bay can be seen the up stream side of the power house, with the gratings or screens at the entrance to the turbine chambers. The Guide wall to the Lock is seen at the left, and between that and the Ice Fender, in the distance, is seen the Movable Dam. This is shown more in detail in Fig. 10. It is 48 ft. long and has an oscillation of 18 ft. from —16 to +2, Chicago Datum. It is an adaption of the Tainter gate, combined with the Bear Trap dam principle. It is operated, however, in a different way from the ordinary Tainter gate.

This movable dam is let down into the pit formed in the masonry, and is lifted by the pressure of water let in through valves below the gate. There are two of these dams,—one 48 ft. long, which controls the elevation of the water in the pool, and the second 12 ft. long, which will dispose of any ice and drift, which may get into the fore-bay. In Fig. 11, is shown the down stream side of these two movable dams. The design is by Mr. L. E. Cooley.

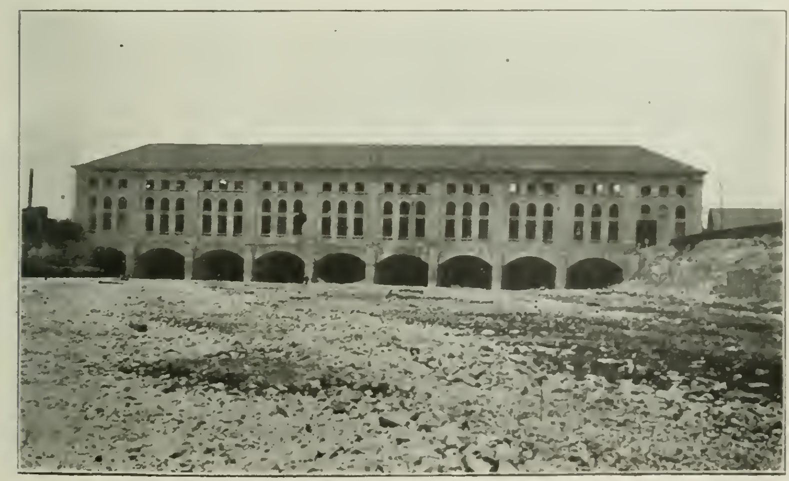


Fig. 8.—Power House, downstream front.

Two views of the Lock are shown in Fig. 12 and Fig. 13. In one of these is shown the stairs reaching to the top of the lock chamber, which is 130 ft. long between quoins and 22 ft. wide, with a lift of 34 ft. The other view gives one a better idea of the depth of the Lock—57 ft., and also shows one of the gates at the north end of the lock. The filling and emptying of the lock will be by means of tubular balanced valves. The gates will be operated by electric power and from either side. We shall have event-

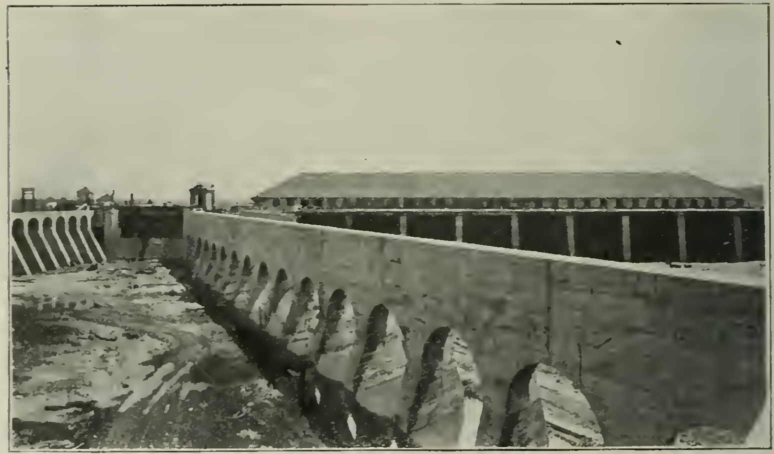


Fig. 9.—Ice Fender.

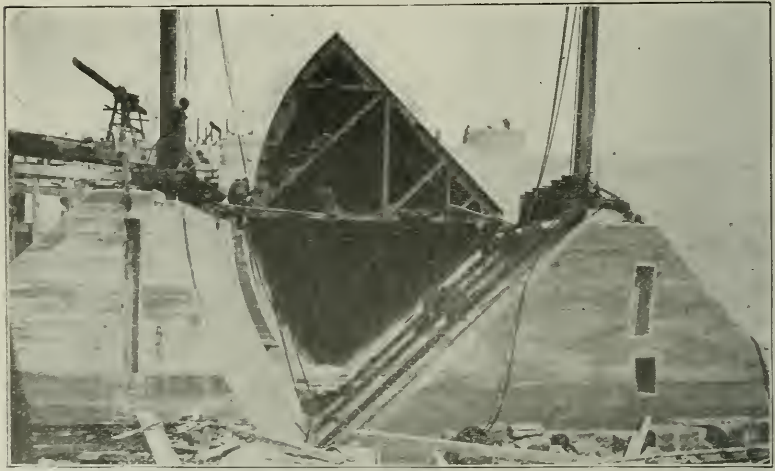


Fig. 10.—Movable Dam.

ually at this Power Plant, if our plans go through, 41,000 electrical horse power.

The new channel below the controlling works, many of the details of which have been described, and which will soon be opened to receive and conduct the water to the Power House, extends to within about 2½ miles of the City of Joliet. The water level in this construction may at times be held up to the level of Lake Michigan, while the general level of Joliet is probably 35 ft. below that.

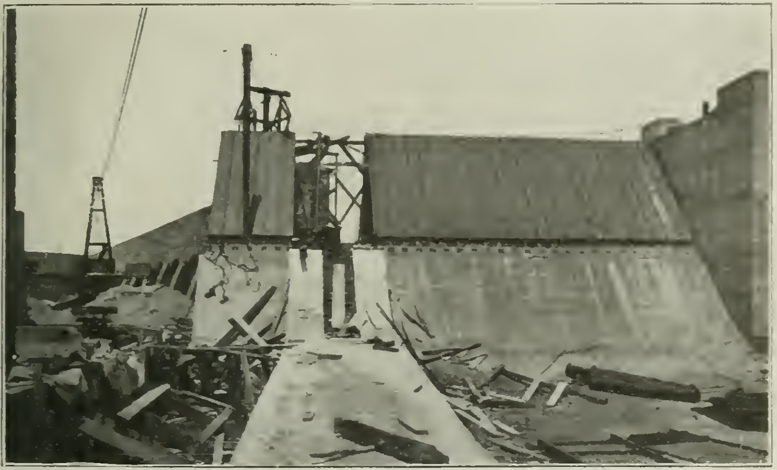


Fig. 11.—Downstream view of the Movable Dams.

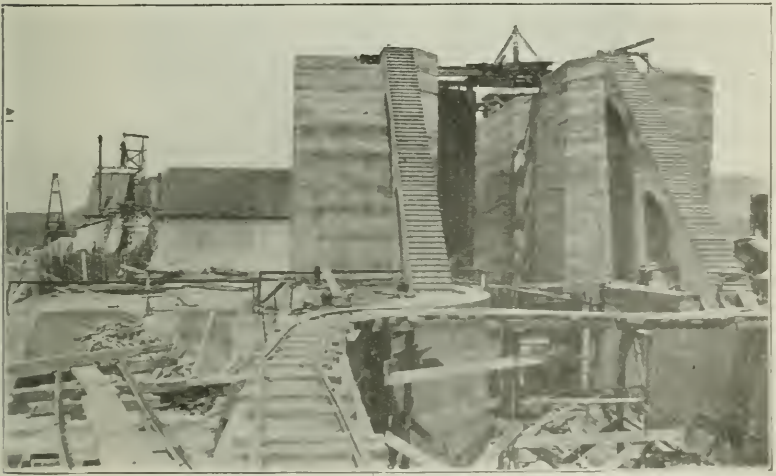


Fig. 12.—Downstream view of Locks.

We have built with a view to such permanence, that a safety device should be unnecessary, but to give every assurance to any timid people, apprehensive of a catastrophe from this body of water, a safety appliance had to be devised and one that would not interfere with the waterway. A movable dam, such as at the power plant, would not do, as it would block the waterway. After a good deal of consideration there was evolved the Butterfly Valve, which has been constructed and installed a short distance below the basin at the Controlling Works. This apparatus consists of a steel diaphragm supported on a central vertical axis upon which it can be rotated, and which will reach entirely across the new channel to above the water level and strong enough to hold up this head of water.

The lower end of the central pivot is securely fastened into the rock bottom, while the upper end of the pivot is held by a bridge, which does not span the stream but is placed lengthwise and anchored to two masonry piers in mid stream. In the large Fig. 14

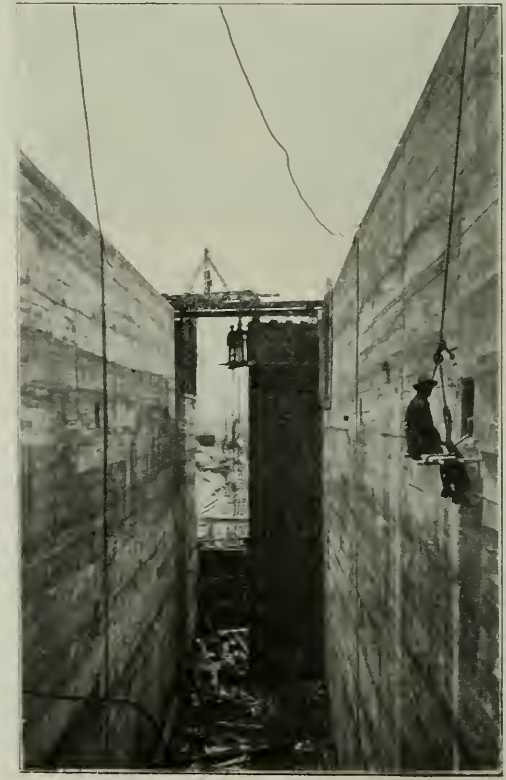
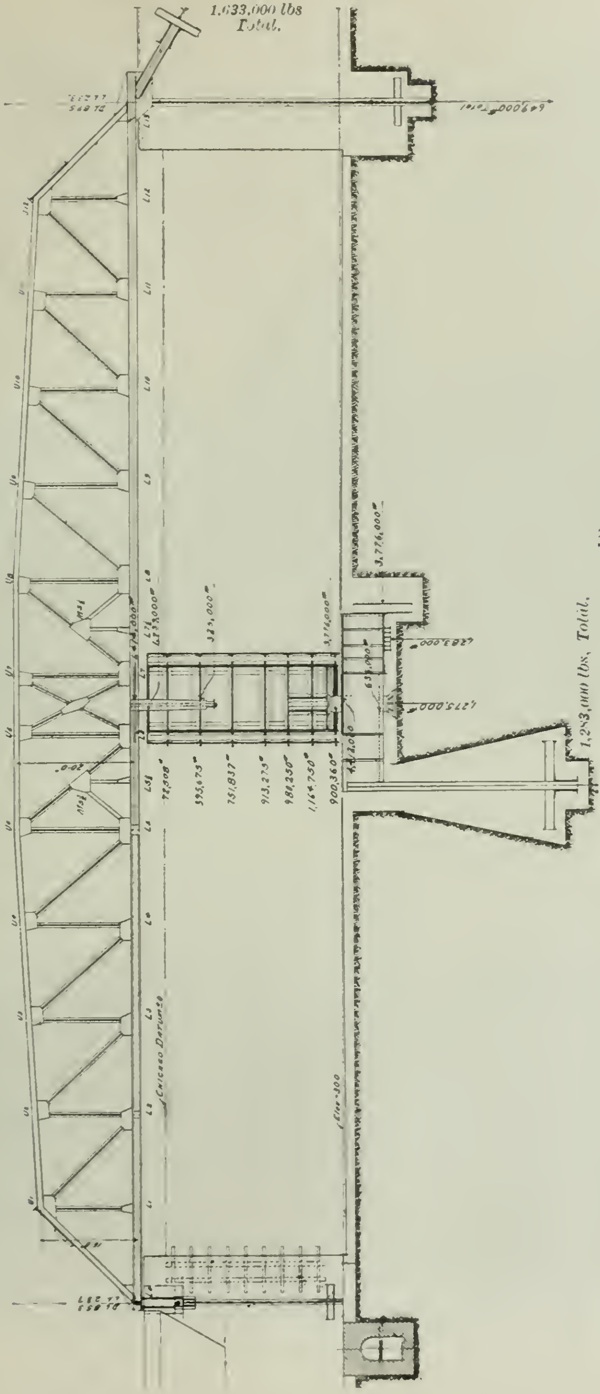


Fig. 13.—View inside Lock, looking north.


1,633,000 lbs
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Chicago Datum
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Fig 14.

is shown the design of the bridge, the pivots and anchorage to the piers. Fig. 15 shows the two piers and Fig. 16 the structural steel diaphragm being erected. Fig. 17 and Fig. 18 show the bridge from pier to pier over the Butterfly Valve. The massive bottom pivot is shown in Fig. 19. In Fig. 20 is shown the up stream face of the valve closing the openings, while Fig. 21 gives the down stream face, under the same conditions. The two water passages on either side of the central piers and valve are 80 ft. wide. This

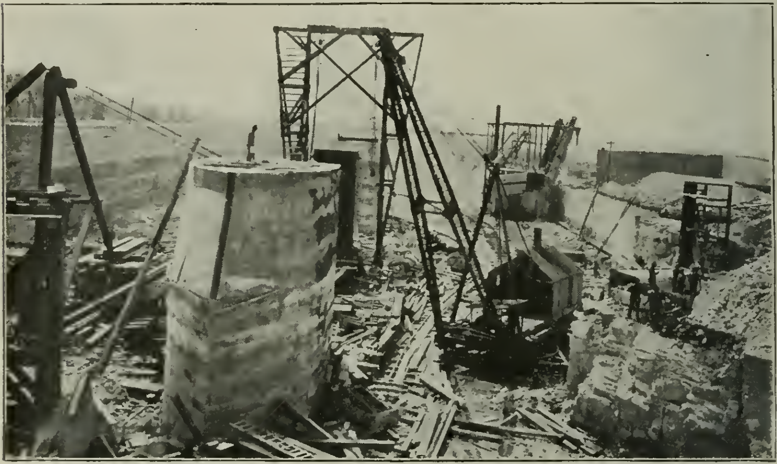

Fig. 15.—Piers for Butterfly Dam.

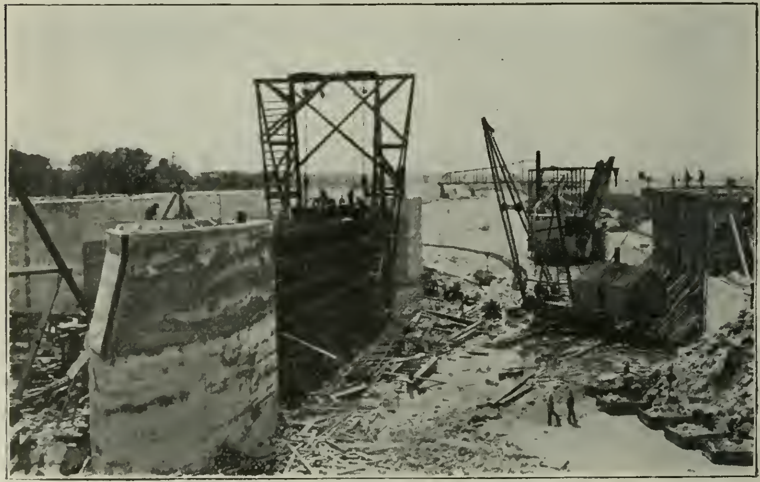

Fig. 16.—Butterfly Dam under erection.

Butterfly Dam is designed of sufficient strength to resist the total pressure of water when the water in the channel above is held up to the level of Lake Michigan, and the channel below the valve is empty. It is so constructed that it will close and may be opened by the pressure of the water against it. Credit is due to Mr. Dart and his assistants in working out the details of construction of this movable dam. When there is no water on the down stream side of this dam, the pressure on the bottom pivot will be 3,760,000 lbs. and the

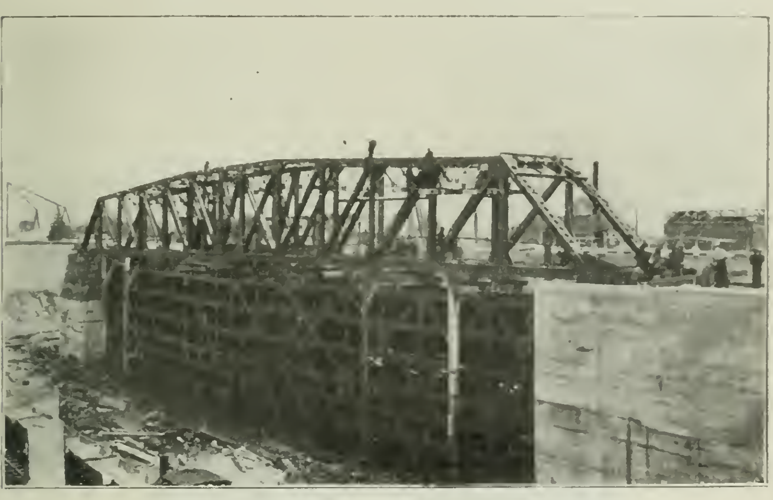

Fig. 17.—Butterfly Dam and Supporting Bridge.

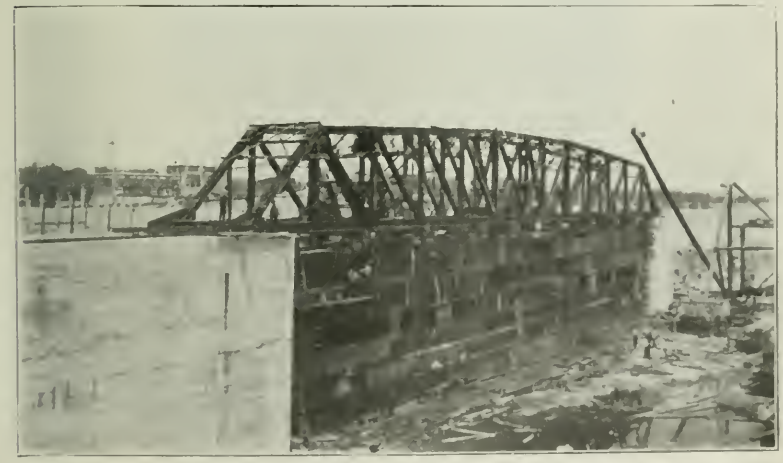

Fig. 18.—Butterfly Dam, upstream face

pressure on the top pivot, which is transmitted through the bridge to the masonry piers, will be 1,739,000 lbs., consequently the whole structure must be of considerable stability.

The operation of the swinging dam is as follows: In each wing of the valve are placed five smaller valves, which will be operated by electric machinery. A rack and pinion mechanism at the upper central pivot and the bridge, similar to that in use with swing bridges, will rotate the movable dam from its normal position. With certain small valves opened and others closed there will be an unbalanced pressure on the two wings of the dam which will swing it across the current against stops in the side wall and close the two 80 ft. passages of the channel. The small valves will be then closed and the dam will shut off the water, except such small amount as may leak by or underneath the dam. To open the dam other small valves will be opened, which allowing the channel below to be filled, will also produce an unbalanced pressure on the wings of the main dam and cause it to revolve back into its normal position.

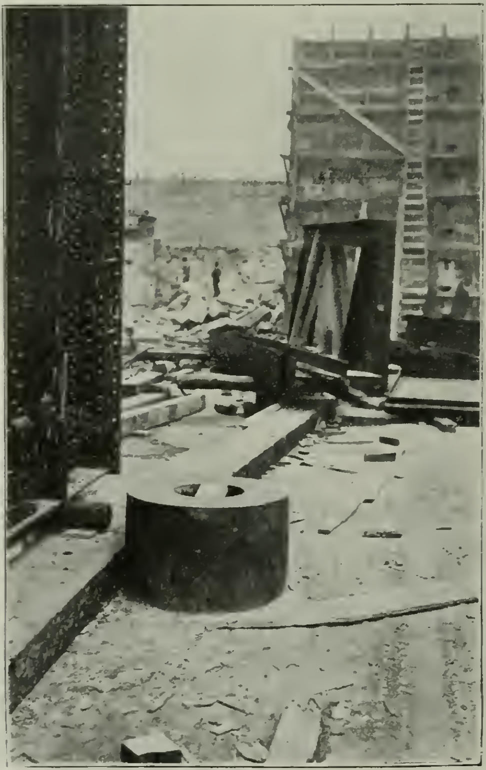

Fig. 19.—Main Pivot of Butterfly Dam.

This structure cost the Sanitary District about $207,000, and while I do not think it will ever be necessary to use it as a safety device, yet it is an investment which ought to be made. It is in the nature of an insurance to the City of Joliet.

In Fig. 22 is shown a map of the Des Plaines River through Joliet and beyond. At the last session of the State Legislature a bill was introduced, the object of which was to empower the Sanitary District to create the second water power at or near Lake Joliet. The plan contemplated was the building of walls through the City of

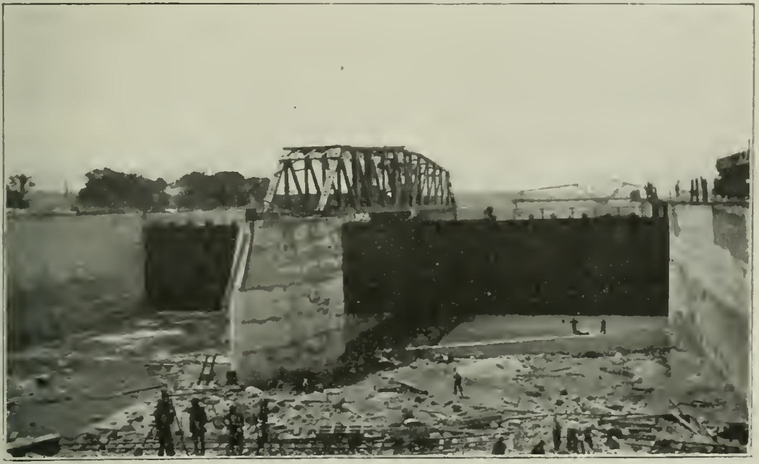

Fig. 20.—Butterfly Dam completed, upstream view.

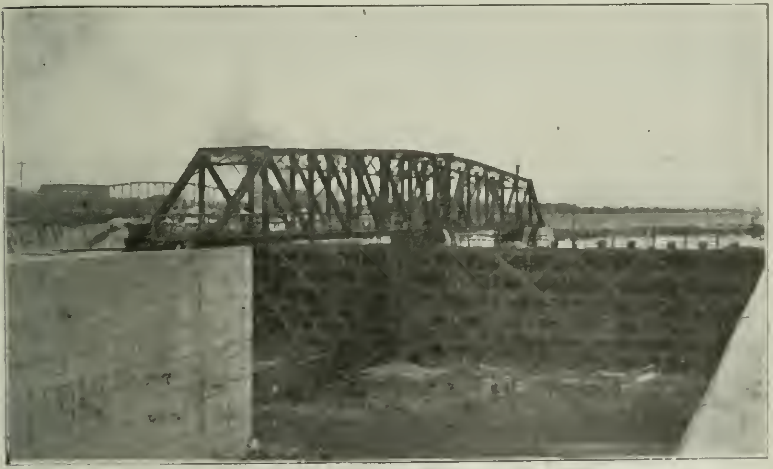

Fig. 21.—Butterfly Dam, downstream face.

Joliet, and the building of a dam and power plant at Lake Joliet of a height which would hold up the water throughout that stretch to an elevation of —40, Chicago datum.

The crest of the dam at the Economy Light and Power Co.'s plant (in Joliet) has an elevation of —42.4, Chicago datum; so if this plan is carried out the water in the present pool above dam No. 1, will stand at 2.4 ft. above the crest of that dam.

The proposition is to make the narrowest part of the channel at Joliet 270 ft. wide and 20 ft. deep. This would necessitate the raising of all the bridges in the City of Joliet, and the building of an intercepting sewer system to take care of the sewage of that City and of the water coming down from the Penitentiary ditch and discharging into Hickory Creek below South Street. This bill was brought up at the last Legislature and was opposed very persistently. The State Legislature convenes again the 8th of October to take up this question and decide whether or not this right be given to the Sanitary District and upon what terms.

The offer of the Sanitary District to the State was that if it were permitted to do this, it would make this a navigable waterway from the Power House to Lake Joliet, but would not build the locks of the large size (necessary for large vessels) which it is expected the Federal Government will build. This project would add about four miles to the deep waterway,—giving such, from Lake Michigan southward for a distance of 40 miles. The right of the Illinois and Michigan Canal is such, that nothing can be accomplished without satisfying that ward of the State. The State owns that canal, of course, and the offer of the Sanitary District is that it will pay $75,000 a year to the Canal for the right to do the work which I have outlined. Of course, it goes without saying that all private owners must be compensated for whatever loss they suffer in this connection. The results of the Sanitary District are quite important as the creation of this second water power (at Lake Joliet) would give them about 80,000 H. P. for sale.

DISCUSSION.

President Abbott: Of course we all expected, when the subject of the meeting was announced, that we were to enjoy a great treat, and I am sure that our expectations have been more than realized.

As Mr. Randolph was proceeding with his lecture I was impressed with one or two things in particular,—One was that in the home of the Joliet building stone industry, he was constructing a building with concrete blocks—artificial blocks. I wondered why he did not patronize that near-by state industry—the stone quarry of the state's prison—instead of manufacturing his own stone. Another point was, Mr. Randolph is not quite certain why he has no ice to bother him at the Controlling Works. He attributes it to microbes contending with each other in the water, thereby raising the temperature. I would ask if he has ever given his two rivals—

the two lighting companies of the city—credit for the 1,500 tons of coal which they burn daily in winter time to warm up the water of his ditch?

Mr. B. J. Ashley, M.W.S.E.: I would ask Mr. Randolph what ingredients he used in making his concrete.

Mr. Randolph: Crushed limestone to a large extent, depending upon the cement to cover and protect the particles of stone from the atmosphere.

Mr. W. S. Monroe, M.W.S.E.: I would ask if the entire flow of the drainage canal is to go through this water-power plant?

Mr. Randolph: Yes.

Mr. Monroe: What will become of the present channel?

Mr. Randolph: The present channel ends at Lockport and the water now passes from there through the Controlling Works into the Des Plaines River. The end of that channel will be cut out so as to let that water all come down into the new channel extending down 10,000 ft. below the present end, and the water will pass down on each side of the Butterfly Valve. The Controlling Works will have no further usefulness except in case of emergency. That will remain there, in case it is necessary to deflect some of the water away from the Power Plant.

Mr. Monroe: When the Drainage Canal is made a Ship Canal, as is the intention, what proportion of the flow of the water will go through the Locks? What is the approximate estimate?

Mr. Randolph: I cannot say just now.

Mr. Monroe: All of the waters going through the locks will be taken away from the supply for the power plant I suppose.

Mr. Randolph: That is one of the reasons for making as large a basin above the power plant as possible, to prevent sudden oscillations of water level at the power plant.

President Abbott: With a Lock such as you describe, which the Government may build, how often could that be filled with the flow of the Canal?

Mr. Randolph: It takes about 20 minutes to pass a vessel through.

President Abbott: It would flood the capacity of that Lock once a minute?

Mr. Randolph: Once in two minutes.

President Abbott: Then by using the entire flow you could "lock" every two minutes, as far as volume of water is concerned, but it would take 20 minutes to get a vessel through, so it would be impossible to use more than 1/10 of the flow for lockage. That would be the maximum. This will answer Mr. Monroe's question I presume.

Mr. J. H. Warder, M.W.S.E.: Can you lock through as often as every 20 minutes?

Mr. Randolph: At the "Soo" they allow, ordinarily, 30 minutes for a vessel to pass through, but it can be done in less time by making a special effort. I think it takes about 8 minutes to fill the Lock at the "Soo" and 8 minutes to empty it; the rest of the time is used by the vessel getting in and out.

President Abbott: I would ask Mr. Randolph what it is proposed to do with this 82,000 H. P.?

Mr. Randolph: We own in that Valley 7,000 acres of land. This land is traversed by a navigable waterway which will float anything that floats in Lake Michigan; and is paralleled by two trans-continental railroads and crossed by four Belt Roads. It is an ideal manufacturing site, and I hope to see that channel lined with manufactories, and those factories using this power. Out of the 7,000 acres must be deducted the width of the channel; a little over 5,000 acres could be made available for power sites.

Mr. D. W. Roper, M.W.S.E.: What would be the objection to using the power to do the pumping at Wilmette?

Mr. Randolph: It is much cheaper to use coal there than to put up a transmission line. Our pole line consists of steel poles 60 ft. high, galvanized. Each pole costs $130.00, besides setting them up. They are spaced 350 feet.

President Abbott: That is only about 40 cents per ft., which is not extremely high. The cost is very small in comparison with the cost of the copper which you would use for the line.

Mr. W. E. Symons: Not being a sanitary or hydraulic engineer I do not feel competent to discuss the subject which has been so ably presented this evening. The matter is one, however, that all transportation people should be interested in, and if they are not interested in it at present, they eventually will be, for the reason that the growth of our country is such that the present transportation facilities, both by rail and water, are now inadequate to supply the demands. The addition of greater transportation facilities is not anywhere near in proportion to the increased demand. The idea which prevailed some years ago, that on the completion of the railways, the canals or waterways had gone out of commission, we have found to be a fallacious one. It is quite true that the railways supplanted the canals at that time, and still will continue to do so in certain forms of transportation, for instance, for perishable goods and passengers who are in a hurry. But the use of canals is going to be called into requisition again; old, abandoned channels will be reopened, new ones will be constructed, and many of our present streams will be canalized for future use. Regardless of the idea which may have come to the minds of railway transportation people, that water transportation is a thing of the past, it is going to be very popular again in the near future, and it is quite proper to suggest—if you will pardon the comment or suggestion—that railroad men might well "sit up and take notice;" also all other people should, I think, extend a helping hand to the end that they co-operate in the furtherresented

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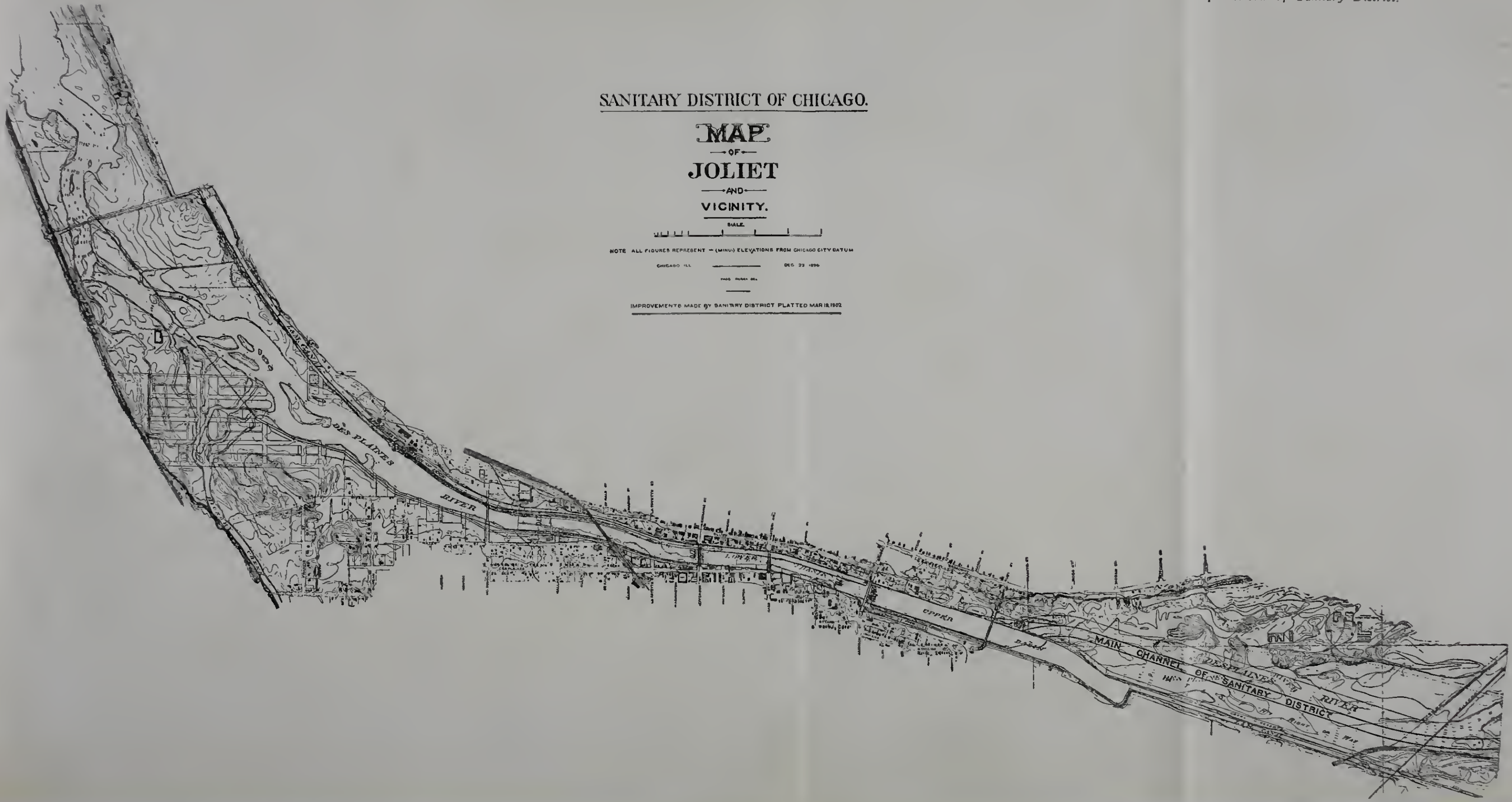
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RIGHT OF WAY

ing of such worthy projects as Mr. Randolph has so ably presented this evening.

Mr. Randolph: In line with the remarks of Mr. Symons I will say that at one of the Deep Waterway Conventions a letter was read from the Vice President of the New York Central and Hudson River Railroad Co., in which he expressed a desire that the waterways of the country might be developed. He said there was no greater example of the merits of the waterways and the advantages to railways than that afforded by the New York Central Railroad; that they were on the line of a waterway and that their prosperity was largely due to the fact that the waterways carried the heavy, undesirable, slow freight and left to the railroads the fast freights and that class of material which could afford to pay a high tariff. He also said that there was a great deal of material that must be carried at a low rate, which meant no profit to the railroads, and all of that class of freight would be carried by the waterways; that the waterways would build up cities and the railroads would get the cream of the business of those cities.

Mr. E. H. Lee, M.W.S.E.: It seems to me that all railroad men must be very much interested both in waterways and in the growing development and uses of electricity. The development of hydroelectric power plants seems to be only in its infancy, and the technical journals in these days are filled with not only instances of great development of power but also with instances of still undeveloped power. The development of electricity by increased economies and the generation of current by steam power is receiving great attention. That is particularly interesting to railroad men because they have had and are having instances of the application of this electric power to their own work, particularly around terminals. We are finding that, in order to get the maximum efficiency out of the facilities that are available in terminals, it is becoming increasingly necessary to use this power. Probably most of the members of this Society will live to see the time when the use of electric energy at all great terminal points—for instance in Chicago—will be quite a matter of course, and that nothing else will be thought of.

President Abbott: The scope of the lecture this evening was the development of an electric power system rather than the development of a ship canal. The inference is that the development of this power in such great quantities would put the Sanitary District in the position of a competitor with the local lighting companies. I think the lighting companies as well as the Sanitary District consider this competition in exactly the same light that the competition of the waterway will be with the railways. The power which the Sanitary District will have for sale will be fully absorbed by industries along its right of way, and will serve only to make a greater Chicago and to put an additional demand upon the lighting companies.

Mr. Randolph: The business of railroads today is congested. I recently looked up the statistics of population of fifteen western states in the middle west, and found that the population—city and country—of those states, gives an average of 31.4 people per sq. mile. What will it be when it gets up into the hundreds per sq. mile? If we cannot take care of the freight traffic pertaining to 31.4 people to the sq. mile, what will we do when we develop such dense populations as they have in the old world. We must develop all of our waterways if anything like these demands come upon us.

IN MEMORIAM.

Oliver Bourne Green,

M.W.S.E., July 12, 1869—Dec. 30, 1906.

A MEMOIR.

A glance at a distance table of a Railway or other public Highway, tells one where it starts, where it ends and the names of the stations along the way, but it conveys no idea of the characteristics of its termini, nor can the mind picture truly for itself scenery along the route; the charm of this or that stopping place named in the schedule, the broad expanse of valley, the shut-in mountain pass, the towering peak or the embosomed lake may all be familiar scenes along the way, but we know them not.

And so it is with the simple chronicle of human life; first comes the date of birth, then the going forth from the shelter of home for school or work, then the date of marriage and last of all the day of life's ending which may be carved upon the tomb, be it the simple head stone or the ostentatious mausoleum. Of the man these things tell us nothing. The chronicle gives us these condensed facts about our trusted friend and honored fellow member, O. B. Green, but no hint is imparted of the endearing traits of his personality.

The chronicle tells us he was born January 1, 1826; that the place of his birth was his ancestral home, Green Hill, Worcester, Mass. We remember how dear that home was to him, how with strong local attachment his heart clung to its memories even to the end. We know moreover that his parents were William E. Green and Julia Plimpton, his wife; that they came from good old New England stock and that they were a godly people. We know, moreover, that he inherited this blessing of godliness, that it was genuine, the guiding force of his life.

He chose the profession of Civil Engineering and 20 years after his birth he was making a survey of the "interior line of the Hudson River Railroad from Albany to Poughkeepsie." One of our members* whom we revere for his worth, his attainments and his ripe experience, writes us—"On the Interior Line I had the pleasure of being flagman for Mr. Green, and on the Shore Line I was advanced to rodman in the level party. Mr. Green was at that time an enthusiast in his profession as a Civil Engineer, very energetic and scrupulous in the discharge of his duty to the Hudson River Railroad Company, often saying 'We are bound to give the Company one hundred cents on a dollar for the money we receive.'"

Mr. Green was first engaged on the location and afterwards in charge of tunnel construction on the Baltimore & Ohio R. R. when it pioneered the march of the railways across the Alleghenys.

In 1855 he removed to Chicago and in 1861 established Green's Dredging Company and made it a success. It was a success because of his capable, energetic management, but better than that it was a success because he put his character into his work. The honor of the man was the pledge of the work done not "with eye service" but with integrity.

He was one of the men who in those early days gave Chicago a start, the momentum of which has ever been accelerating.

He built the Sturgeon Bay Canal and the Canal between Petoskey and Cheboygan in Northern Michigan.

In 1855 Mr. Green married Emily Louise Pomeroy who survives him, together with three children; Mary Pomeroy, Andrew Hugh Green and Mrs. Wyllys W. Baird. He was a brother of the late Andrew H. Green, "Father of Greater New York."

The strong human sympathies which possessed Mr. Green prompted those good deeds which are remembered so gratefully by many humble recipients. The Editor of one of our great city papers said to one of us when talking of the subject of this memoir, "he not only gave his money but he gave himself; he would visit those who were in trouble and 'hearten them up' with his kindly sympathy. The Passavant Memorial Hospital was an object of deep interest to him and to it he gave time, thought, work and money."

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*Richard Price Morgan.

All this is well told in the report of that Hospital for 1906 and we can from our hearts concur in one of its statements, "We loved Mr. Green for himself."

As long as we remember the pleasant things of life we will cherish the recollection of his quaint and genial humor and his bright sayings. Old age was gentle with him and he passed into the beyond, in blessed hope of immortality on December 30, 1906. The Western Society of Engineers may well be proud to remember that O. B. Green was one of its Charter Members.

(Signed)
ISHAM RANDOLPH,
FRED DAVIS,
G. A. M. LILJENCRANTZ,
Committee.

ARCHIBALD MACARTHUR.

Mr. MacArthur was born at Mount Morris, N. Y., June 15th, 1834; he died at Riverside, Ill., June 1st, 1907. More than fifty years ago he began his life work as a Contractor, with his father, John R. MacArthur. In 1857, with his brothers William and James, he established the firm of MacArthur Brothers, the business of which extended over a wide territory in the East, until 1873, when its headquarters were fixed in Chicago.

During the early construction of the Erie Canal, the MacArthur Brothers were almost constantly engaged upon that work. That this work was faithfully done is evidenced by its uninterrupted use until this day.

East, West, North and South are railroads, canals, great bridges, dams, tunnels and other works of great magnitude, enduring monuments of the perseverance, energy and ability of these men.

In his long experience, during which the methods of his profession have been revolutionized Mr. MacArthur kept abreast and often in advance of his fellows. He was quick to discern and prompt to avail himself of new ways and means of facilitating and improving his work. He gave careful consideration to details, and was seldom wrong in his estimate of men and things. He has been fittingly designated as the dean of the contracting profession.

He became a member of the Western Society of Engineers November 7th, 1894, and always maintained his interest in whatever would tend to its advancement and welfare. His love of justice, his kindly disposition, his regard for the rights and feelings of others and his generosity won for him the friendship and respect of all with whom he came in contact and endeared him to his intimate associates.

Through more than a half century of constant and conspicuous achievements in a profession abounding in unusual temptations to dishonest conduct, not the shadow of a suspicion of wrongdoing ever dimmed the lustre of his spotless integrity.

"An honest man is the noblest work of God."

(Signed) Wm. Sooy Smith,
David Sloan,
Committee.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF EXTRA MEETING, June 26th, 1907.

An extra meeting (No. 608) was held Wednesday evening, June 26th, 1907. The meeting was called to order about 8:15 p. m. with President W. L. Abbott in the Chair and about 85 members and guests present. There was no business to bring before the meeting, so the speaker, Past-President Isham Randolph, Chief Engineer of the Sanitary District, was introduced by the Chairman, who addressed the meeting on "The Work of the Sanitary District south of the Controlling Works at Lockport: what had been done and what was in contemplation." The address was illustrated with many stereopticon views, relating particularly to details of construction of the Hydro-Electric Power Development between Lockport and Joliet.

Discussion followed from Messrs. Abbott, Ashley, Monroe, Roper, Symons, Lee and Warder.

The meeting adjourned about 10:15 p. m.

J. H. Warder, *Secretary.*

BOOK REVIEWS.

Water Works Management and Maintenance: By Winfred D. Hubbard. Asso. M. Am. Soc. C. E., and Wynkoop Kiersted. M. Am. Soc. C. E., 8vo., 429 pages, 114 figures, 18 plates, cloth, $4.00, John Wiley & Sons, New York, N. Y. 1907.

The time once was, when farmers pursued the cropping of their lands year after year without acquiring much if any knowledge of the ability of the soil to produce a satisfactory crop of any particular cereal or vegetable other than such knowledge as might be acquired in consequence of occasional or repeated failures. They were students of nothing in particular. Times are changing and the most successful husbandmen of today must be and are fast becoming students of agriculture, for our progressive times demand it, if successful attainments are arrived at. So is it with the managing and maintenance of Public Utility Plants. The manager of such Plants must now be something more than what heretofore has been regarded as merely a "good business man." The good business man of today must be possessed of some technical knowledge of the utility he expects to maintain and operate if he would succeed financially or satisfy his constituency or patrons. His chief assistants should also be students as much if not more than the manager. Hubbard & Kiersted's "Water Works Management and Maintenance," just published, will answer the increasing needs of water works' owners, managers and superintendents everywhere. It is essentially a work suited to the uses of the practitioner more than to the uses of the designing expert. It begins at the basis of the service and gives an able discussion of the various subjects with which the "man at the wheel" has to deal, yet the subjects are so condensed and plainly dealt with as to be of practical everyday use. Very practical information is given regarding ground and river waters and their biological and chemical constituents together with methods for collection, determination and purification and in such a form as to be readily understood by the ordinary student of Water Works Plants and their operation. By reason of the knowledge to be gained by familiarizing ones self with the contents of this book, the value of their services as such manager or assistant cannot fail to be enhanced. What a pumping engine should be and the duty it should be able to perform is quite clearly given together with a few simple formulae that will enable the Superintendent of Works to determine whether his pump is doing its full or best duty and if doing it economically or not. That the location of water mains and services may not be lost, a scheme for intelligently recovering all constructional work is outlined together with a review of the various designs of Hydrants, Valves and Boxes.

The forms of service connections and water cocks used in connection; water meters, their emplacement and care and the alteration of appurtenances and many other points of lesser detail all receive due consideration in this volume and the suggestions rendered regarding their character, suitableness and emplacement are valuable.

One of the most serious needs in water works management is that of producing a steady maintenance of quality as well as suppressing needless waste. This subject has been given sufficient attention to enable managers oftentimes to prevent contamination by the adoption of simple means and to detect and prevent such useless waste. We, however, must criticize the work because of the absence of a more complete and comprehensive table of cities, their population and their water consumption. One cannot prove the averaged quantity consumed by depending on the experience of any single city of a stated population. A dozen or more cities of any certain population would more certainly give a basis for quantity of water consumed per capita per diem than can be arrived at by the recital of the experience of a single city of its particular class.

One cannot read or study the chapter on Electrolysis without getting a pracical idea of what is necessary to prevent it. Part 3 on Franchise, Water Rates and Depreciation will be found of much value to the owner and also to the municipality in the event of franchise terminations or sale.

As a whole, the volume is intended for the practical everyday use of the active manager, superintendent, repairman or engineer of a water works plant and the library of any water works official or operator will be incomplete without this useful help. The volume will also be of considerable and practical use, to the amateur designing engineer and valuable as a ready reference to all subjects comprised in the treatise. We opine that this work will find a distinct place among the needs of successful water works' managers or assistants. B. J. A.

ALLOWABLE PRESSURES ON DEEP FOUNDATIONS: Elmer L. Corthell, M. W. S. E., 12mo., 98 pages, 8 folding tables. Cloth, $1.25. John Wiley & Sons, New York, N. Y. 1907.

Mr. Corthell has done a peculiar and useful piece of work. Finding himself called upon to give an opinion upon the allowable pressures on foundation materials of an important structure, and that his own experience as well as that of others obtainable at that time, either in books or reports, was not sufficient to give all the information necessary on which to base an opinion, in 1902 he inaugurated an investigation upon the safety of foundations, for the benefit of the profession. Failing to find some young engineer who would, out of love for his profession, assist him in this work, he decided to employ an expert at his own expense and selected Mr. Charles R. Wychoff, Jr., then assistant to Prof. Burr of Columbia University.

A circular letter was issued December 5, 1902, and sent to about 300 engineers in various countries, with a blank form covering 21 inquiries. To this the answers were disappointing, not one-tenth of the addressed sending back useful data. These were supplemented by Mr. Wychoff through a study of published data to be found in periodicals and professional papers to Engineering organizations, as well as by correspondence.

The result has been the compilation of 8 tables containing data more or less complete, in reference to 178 works, which may be summarized as follows:

PRESSURE ON STRUCTURES. NET TONS PER SQUARE FOOT.

Material	Minimum	Maximum	Average	Remarks
Fine Sand	2.25	5.80	4.50	10 cases, no settlement
Coarse Sand and Gravel	2.40	7.75	5.10	33 " " "
Sand and Clay	2.50	8.50	4.90	10 " " "
Alluvium and Silt	1.50	6.20	2.90	7 " " "
Hard Clay	2.00	8.00	5.08	16 " " "
Hard Pan	3.00	12.00	8.70	5 " " "
Fine Sand	1.80	7.00	5.20	3 " notable "
Sand and Clay	1.60	7.40	3.30	3 " " "
Alluvium and Silt	1.60	7.60	4.60	2 " " "
Hard Clay	4.50	5.60	5.20	5 " " "

This table (tabulated by reviewer) illustrates once more that no hard and fast rule can be predicated upon the name which is offered to each material and that the engineer must discriminate for himself. For instance, "fine sand," loaded from 2.25 to 5.80 tons per square foot shows no settlement in 10 cases, but other fine sands loaded with 1.80 to 7.00 tons per square foot show a notable settlement in 3 cases.

The unsatisfactory feature in the investigation is that reports were only obtained of 13 failures to carry the weights imposed. Men do not like to tell of their failures, but as the author writes, a discussion of his paper is to be hoped for and that further data will be contributed by engineers concerning failures and the circumstances pertaining to them, so as to present as large an array of facts as possible.

The reader should be cautioned that some misprints will be found in the book. O. C.

PROBLEMS OF THE PANAMA CANAL: By Brig.-Gen. Henry L. Abbot, U. S. Army, Retired. Member U. S. Board Consulting Engineers. Cloth, 6 by 8½ ins., pp. 269, including index, with illustrations. Many tables and diagrams. New York. 1907. The Macmillan Co. Price, $2.00 net.

This book by Gen. Abbot, originally published in 1905, has now been revised and brought down to date. All of the latest climatic and hydraulic data and the latest plans for the canal are included in the book and thoroughly discussed. For a period of seven years, the author was actively connected with the canal project, first as member of the Technical Committee of the New French Company, and later as member of the U. S. Board of Consulting Engineers. He is therefore in a position to write authoritatively on his subject. The difficulties involved in building and operating the canal may be roughly grouped for convenience into the two following problems:

The Cut through the Continental Divide.

The Control of the Chagres River and its affluents, including as it does, the location and type of the great dam for impounding the waters of this river.

Closely associated with both of these problems is the question of summit level of the canal, involving the number, location and lift of the locks.

Formerly a serious problem, was the question as to a canal at sea level or a lock canal. With the decision of the U. S. Government to build a lock canal, the visionary scheme of a canal at sea level was happily laid at rest. The cut through the Continental Divide is a tremendous undertaking, but it is a problem of construction only. Once done, it may be considered as permanently disposed of. A considerable part of this excavation was done by the French Company and great progress has been made since the transfer of the canal to the U. S. Government.

Probably the most serious question of all is the Chagres River. The operation of the canal must always be intimately associated with the control of this river. The control of excessive floods during the rainy season, and the storage of water for use in lockage during the dry season furnish problems for which various solutions have been proposed. The variation in flow can be best understood from the statement that the maximum discharge at Bohio, during the great flood of December, 1906, was 108,000 cubic feet per second, while the discharge often falls as low as 500 cubic feet per second during the dry season. The author is a firm adherent of the dual lake plan. proposed by the French Company. This contemplated a dam at Bohio for forming the main lake, and a second dam at Alhajuela, ten miles from the line of the canal, for catching the flood waters of the Chagres and holding in reserve for use during the dry season. The plan adopted by the U. S. Government provides for a single lake, with a summit level 23 feet higher than that proposed by the French Company, and a dam at Gatun. These two plans are thoroughly discussed by the Author. It is clear that the dual lake plan was a good one, perhaps the best solution of the question, and the reader is apt to believe that a mistake was made in abandoning it. The dam proposed at Gatun, is of enormous dimensions, the base being practically half a mile wide. A number of interesting plans have been proposed for a dam across the Chagres valley, that of the late Geo. S. Morison for a dam at Bohio may be mentioned as the most striking. This consisted of two rock fill dams, approximately half a mile apart, with the space between them filled with earth. A serious problem with a dam at any point in the lower end of the valley is the prevention of percolation through the permeable material lying far below the surface of the ground.

One chapter of the book is devoted to a somewhat detailed discussion of the two routes, Nicaragua and Panama. The old controversy between the advocates of these routes is now fortunately a thing of the past, but the discussion is interesting in both a historical and technical way. In reading the book, one is impressed with the vast amount of valuable data that has been collected, bearing on the problems of the canal. J. E. M.

TIN DEPOSITS OF THE WORLD, WITH A CHAPTER ON TIN SMELTING: By Sydney Fawns, F. G. S. The Mining Journal, London, 1907. Full cloth; 304 pages; 6 by 8½ ins., with many illustrations, tables, index and bibliography. This is a second edition of the work published in 1905, and reviewed in the Journal, Vol. XI, page 129, but the book has been considerably enlarged and has a greater number of illustrations. Price, 15 shillings.

Chapters I and II give the early history of tin mining and descriptions of tin deposits. Chapters III and IV describe the alluvial tin deposits of the Malay Peninsula, Straits Settlements, British Burma and French Indo-China. Chapter V describes alluvial tin mining, generally by hydraulicing, Chapters VI to XIV inclusive describe the tin deposits at various tin mining centers over the world, some of which are but of minor importance, but others of great value. Chapters XV and XVI describe more in detail the noted tin mines of Mount Bischoff in Tasmania and of Dolcoath in Cornwall, the latter of which is the largest tin producer in England and was worked successfully 160 years ago. Chapter XVII describes crushing and dressing machinery, while Chapter XVIII treats of dredging for tin, with descriptions of machinery, dredges, etc., and operations. Methods of tin assaying are given in Chapter XIX, and of tin smelting in Chapter XXI. Statistics forms the subject of Chapter XX.

Considering the limited amount of literature on this subject, the book should be of value to mining engineers and others interested in the matter. The operation of mining by hydraulic process with jets of water under considerable pressure is of value to mining engineers, in other lines than that of tin. W.

PUNCHES, DIES AND TOOLS FOR MANUFACTURING IN PRESSES: By Joseph V. Woodworth, M. E. 467 pp., including an index and with more than 700 illustrations. Cloth, 6 by 9 ins. Price, $4.00. Published by Norman W. Henley Pub. Co., New York. 1907.

This is a valuable addition to the literature on this subject. The author has taken up the work in sections treating first the simple bending processes, then blanking, forming and combination dies, feed mechanisms for automatic production, drawing dies and various manufacturing processes, as developed by users of the punch press. There are also many useful suggestions in regard to the design and construction of dies and attachments for producing stampings rapidly and accurately.

The text is illustrated by examples of work and tools that have been designed to produce this class of work in a satisfactory manner.

The rapid advance this method of manufacture has made in recent years is seen on all sides. The ingenuity shown in the construction of many of this class of tools is a surprise to those not in touch with this particular method of production. These processes have been developed to such an extent in late years that no man working alone can hope to be personally familiar with the large field of application for this method of production.

This work, is, as it claims, a cyclopedia of methods and processes that may be used as reference showing a wide range of work and suggestions to the designer or mechanic, as to ways of doing a large variety of work of similar character. It is devoid of any troublesome technical discussions or formidable mathematics and should appeal very strongly to the practical mechanician, interested in this line of work. T

TOOLS FOR MACHINISTS AND WOODWORKERS: By Joseph Horner, author of "Pattern Making" and other kindred shop subjects. 333 pp. with index; 456 illustrations. Cloth bound, 5½ by 8 ins. Price, $3.50. Published by Norman W. Henley Pub. Co., New York.

A careful reading of this work will impress the reader with its decided "practicalness,"—a work, the perusal of which will be of permanent benefit to the engineer, machinist or woodworker.

Chapter XIX, treating of "Standards of Measurement," is a very practical and interesting one. It gives to the student an emphatic impression of the intimate relation that standardization should maintain with the manufacture of any useful article or machine.

There are some discussions, influenced, no doubt, by local conditions in foreign practice which do not accord with the most approved American practice. For example, the position of the cutting tool with respect to the axis of the work, or the use of tools suitable for cast iron or steel on brass or gun metal. The chapter on Tool Angles is worthy of special mention.

The book is well gotten up, and very well illustrated. It is to be commended to students in the manual training and engineering schools.

T.

MODERN STEAM ENGINEERING: By Gardner D. Hiscox, M. E. Includes section on Electrical Engineering, by Newton Harrison, E. E. Well illustrated. 6½ by 9½ ins., cloth, 476 pp. with index. Price, $3.00. Published by Norman W. Henley Pub. Co., New York.

A careful perusal of this book impresses one with the care that the author has used in fulfilling his purpose, as outlined in the preface, to "meet the wants of the student and engineer in all the practical requirements" pertaining to the application of steam power.

The discussions pertaining to design or performance are devoid of any "formidable" mathmatics and well within the range of usefulness for those with only a good training in arithmetic.

The sections giving many questions pertaining to plant operation, with answers, will appeal to the practical man in trouble or the student seeking an engineer's license.

The tables contained are such as may be found in most hand books and catalogs, but some care has been exercised in choosing the most important ones for this work.

The electrical section presupposes some considerable knowledge of electricity and magnetism, and dynamo electric machinery but is presented in a clear and simple manner.

The book might be adversely criticised for the lack of logical grouping of the subject matter into chapters and for the failure to point out the approved practice where a number of authorities are cited with differing opinions pertaining to certain subjects, such as the design of machinery details.

The author is to be commended for the careful attention given to the flow of steam through orifices, nozzles, etc., superheated steam, and the steam turbine; subjects which are of such vital importance to present day practice. J. C. T.

A TEXT-BOOK OF ELECTRO-CHEMISTRY: By Professor Max LeBlanc, University of Leipzig. Translated from the Fourth Enlarged German Edition by Willis R. Whitney, Ph.D., Director of the Research Laboratory of the General Electric Co., and John W. Brown, Ph.D., Director of the Research and Battery Laboratory of the National Carbon Co. Cloth, 338 pp.; illustrated. Price, $2.60. The Macmillan Co., New York. 1907.

It is particularly satisfactory to note the appearance of a good English translation, so nearly simultaneously with that of the Fourth German Edition of this excellent text book.

While it will be necessary for the Engineer, not well grounded in Chemistry, to study the text carefully, for full comprehension, the matter is so well and methodically arranged that for one at all prepared to take up the subject, the work is unusually clear.

The fact that both the translators are engaged in research connected with prominent industrial establishments, no doubt, accounts in a large measure, for the very practical presentation of the work.

Chapter I deals with the forms of Energy and their measurement, and the fundamental principles relating to Electrical Energy.

Chapter II includes Electro-Chemistry historically considered, bringing it up to the present time.

Chapter III explains the theory of Electrolytic dissociation, which is followed by a discussion of the migration of the Ions.

In its practical bearing, perhaps, there is no more important part of the work than Chapter V, treating of the Conductance of the Electrolytes.

Electrical Endosmose, the Migration of Suspended Particles and of Colloids, forms a brief but important subject of Chapter VI.

Electromotive Force is comprehensively dealt with in Chapter VII, followed by a chapter on Electrolysis and Polarization.

A supplement, on Storage Cells is included in Chapter IX, and the book closes with a full explanation of the notation consistently used by Messrs. Whitney & Brown throughout the book. The index is fair. The work can be unhesitatingly recommended as reliable, practical and readable.

W. H.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for April, 1907, we have the pleasure to report the following additions to the library and gifts rom donors named:

MISCELLANEOUS GIFTS.

A. R. McAlpine, Chicago, "Waterproofing, particularly as applicable to masonry and concrete structures," by E. W. DeKnight. Pam.

University of Illinois, Urbana, two pamphlets, "Tests of Reinforced Concrete T-Beams," and "Tests of Concrete and Reinforced Concrete Columns," by A. N. Talbot.

University of Montana, Missoula, President's Report, 1905-6. Pam.

Burlington, Vermont, Health Officer; Annual Report dated January 1st, 1907. Pam.

University of Michigan, Ann Arbor, Calendar 1906-7. Pam.

Manchester N. H., Board of Health, Annual Report, City of Manchester, 1906. Pam.

P. Blakiston's Son & Co., New York, "The Bacteriological Examination of Water Supplies," by W. G. Savage. 1906. Cloth.

Edward A. Bond, Chairman Advisory Board of Consulting Engineers, State of New York. Report upon work relating to Barge Canal, 1906. Pam.

Ohio State Highway Department, Columbus, O., Bulletin No. 8, Road Laws of Ohio. Pam.

F. S. Shields, Sec'y, New Orleans Sewerage and Water Board, Semi-annual reports, 1900-6. Pamphlets.

J. Willard Morgan, Comptroller, State of New Jersey Railroad and Canal Reports, 1906. Cloth.

W. J. Wilgus, Vice-Pres. N. Y. C. & H. R. R. R. Co., New York, "Standard Plans and Specifications." Two bound volumes.

City Engineer and Park Superintendent, Mankato, Minn. Annual reports for 1906. Pam.

Illinois Board of Charities, Springfield, Ill. Quarterly Bulletin, January, 1907. Special Bulletin, April, 1907. 2 Pams.

J. H. Warder, Sec'y W. S. E., Chicago, "A Treatise on Ore Deposits," by Frederick Prime, Jr. 1870. Cloth.

"Architectural Iron Work for Buildings," by Wm. J. Fryer, Jr. 1876. Cloth.

Edwin Duryea, Jr., Chief Engineer, Bay Cities Water Co., San Francisco, "Bay Cities Water Company's Water Supply for San Francisco," by Edwin Duryea, Jr. March, 1907. Pam.

T. W. Jaycox, Colorado State Engineer, Reports of State Engineer, 1881, 1882, 1905, 1906.

Mass. Board of Railroad Commissioners, 38th annual report of Commissioners for 1906. Cloth.

Lowell, Mass., Water Board. 34th annual report for 1906. Pam.

The Mining Journal, London. "Tin Deposits of the World," by Sydney Fawns, 2nd ed., 1907. Cloth.

Commissioners of Wisconsin Geological and Natural History Survey, "Clays of Wisconsin and Their Use," by Heinrich Ries. 1906. Cloth.

Superintendent of Immigration, Ottawa, Canada. Points of interest in Canada. Cloth.

Armour Institute of Technology, Chicago, 14th Annual Year Book, 1906-7.

Boston Society of Civil Engineers, Constitution and By-Laws and List of Members, May, 1907. Pam.

Columbia University. Lists of the Alumni of the Schools of Science of Columbia University. 1905. Pam.

University of Illinois, Register for 1906-7. Pam.

Iowa State College of Agriculture and Mechanic Arts. Catalogue 1907-8.

University of Kansas. Alumni Catalogue, February, 1905. Pam.

Lehigh University. Register 1906-7. Pam.

Lewis Institute, Chicago. Announcement of courses for 1907-8. Pam.

University of Maine. Annual Report for 1905. Pam.

Massachusetts Institute of Technology. Register of Graduates, March, 1907. Pam.

University of Michigan, Dept. of Engineering. General Announcement 1907-8. Pam.

University of Minnesota, Directory of the Alumni of the University of Minnesota, Dec., 1906. Pam.

University of Missouri, Alumni Directory, Dec., 1906. Pam.

Ohio State University, Alumni Register, November, 1906. Pam.

University of Pennsylvania, Catalogue 1906-7. Pam.

Polytechnic Institute of Brooklyn. Fiftieth Annual Catalogue, 1905-6. Pam.

Rensselaer Polytechnic Institute. Catalogue March, 1907. Pam.

Rose Polytechnic Institute. Annual Catalogue 1907.

Stevens Institute of Technology. Annual Catalogue, 1907-8. Pam.

Tufts College, Dept. of Engineering. Catalogue 1906-7.

University of Wisconsin, Catalogue of Officers and Graduates 1849-1907.

Worcester Polytechnic Institute. Catalogue 1906-7.

Yale University. Directory of Living Gratuates. 1906. Pam.

Purdue University, Lafayette, Ind. Register of the Alumni, 1875-1906.

Society of Engineers, London. Transactions for 1906. Cloth.

Illinois Society of Engineers and Surveyors, 22nd Annual Report, 1907.

Association of Ry. Supts of Bridges and Buildings, Proceedings, 16th annual convention. 1906. Pam.

Canadian Mining Institute, Montreal. Journal for 1906. Vol IX. Pam.

Iowa Geological Survey, Annual report for 1905. Vol XVI. Cloth.

University of Wisconsin, Madison, Wis., Bul. No. 145 and 148, Engineering Series, November, 1906. Pam.

Illinois Highway Commission, First Annual Report, 1906. Pam.

Institution of Electrical Engineers, London, Proceedings, November, December, 1906. Part. 181. Pam.

Missouri Bureau of Geology and Mines, Biennial Report of State Geologist, 1906. Pam.

Railway Signal Association. Proceedings for 1907. Pam.

Lake Superior Mining Institute. Proceedings 12th annual meeting, 1906. Pam.

W. E. Emery, Sec'y Roadmasters and Maintenance of Way Association, Proceedings, 22nd, 23rd and 24th annual meetings, 1904-5-6. Pams.

American Electrochemical Society, Transactions, 1906. Vol. X.

Nova Scotian Institute of Science, Halifax. Proceedings and Transactions, 1903-4. Vol. XI, Part. 2.

Royal Society of New South Wales, Journal and Proceedings, 1905. Vol. 39. Pam.

American Society for Testing Materials. Proceedings, 9th annual meeting, 1906. Vol. 6.

University of Montana, Missoula, Mont. Register for 1906-7. Pam.

University of Montana, Missoula. Announcement 4th Annual Inter-scholastic meeting for 1907; and 9th Annual Announcement Biological Station at Flathead Lake. Pams.

G. H. Hillebrand, M. W. S. E., Chicago. Proc. of Board of Trustees, Sanitary District of Chicago, 1906.

State Agricultural College, Ft. Collins, Colo. Catalogue and Prospectus, 1907-8. Pam.

Smithsonian Institution, Washington, D. C. Classified list of Smithsonian Publications. April, 1907. Pam.

Scientific Publishing Co., Manchester, England. How to design a Gas Engine, by Horace Allen. 1907. Cl.

R. Modjeski and Alfred Noble, M. W. S. E., Chicago. The Thebes Bridge. 1907. Cl.

John Wiley & Sons, New York. Water Works, by Hubbard. Cl.

Boston Street Dept., Boston, Mass. Annual Report of Street Dept. for 1905. Cl.

Engineering News Publishing Co., New York. Spec. for Street Roadway Pavements, by S. Whinery. 1907. Pam.

Theo. N. Ely, Chief of Motive Power, Penna. R. R. Co. Locomotive Tests and Exhibits, Penna. R. R. System at Louisiana Purchase Exp. Cl.

Metropolitan Water & Sewerage Board. Sixth Annual Report, Jan. 1, 1907. Cl.

National Rivers and Harbors of Congress, Washington. Proc. of convention. December, 1906. Pam.

E. E. R. Tratman, M. W. S. E., Chicago. Report of Special Telephone Commission, April, 1907. Pam.

Report of General Manager of Rys. of Cape of Good Hope for 1906. Pam.

The Illinois and Mississippi Canal, by F. W. Honens. Pam.

City of Baltimore, Calvin W. Hendrick, Chief Engineer, Sewerage Commission. Annual report of Sewerage Commission for 1906.

The Mining Journal, London. Gold Dredging by Capt. C. C. Longridge, 1907. Cl.

John Wiley & Sons, New York. Allowable Pressures on Deep Foundations, E. L. Corthell, 1907. Cl.

GOVERNMENT PUBLICATIONS.

Department of Commerce and Labor, Bureau of the Census, Bulletins 64, 66, 67, 70 and 71.

U. S. Dept. of Agriculture, Farms Bul. 277, The Use of Alcohol and Gasoline in Farm Engines; by Lucke and Woodward. Pam.

U. S. Dept. of Agriculture, Office of Public Roads, Bul. 28, The Decomposition of the Feldspars. 1907. Pam.

U. S. Dept. of Agriculture, Forest Service.

Circulars 54 to 78 inclusive; also 80.

Bulletin 74; Forest products of the U. S. 1905; by R. S. Kellogg.

U. S. Geol. Survey, Dept. of Interior, Reclamation Service, 4th annual report of Reclamation Service, 1904-5. Paper.

U. S. Geol. Survey, Dept. of Interior, Bulletins 279, 286, 297, 303, 305, 306, 307 and 310. Pams.

Monograph No. 50. 1906. Cloth.

Mineral Resources of the U. S. 1905. Cloth.

Water Supply & Irrigation Papers Nos. 182, 183, 187-9.

Mineral Products of the United States in 1905. Pam.

27th annual report of Director of U. S. Geological Survey, 1905-6. Pam.

The Production of Gold and Silver in 1905. Pam.

The Production of Gas, Coke, Tar and Ammonia in 1905. Pam.

Black Sands of the Pacific Slope in 1905. Pam.

U. S. Navy Department, Washington, D. C., Annual report, Chief of the Bureau of Steam Engineering, 1906. Pam.

Interstate Commerce Commission, 20th annual report, 1906.

Interstate Commerce Commission, 18th annual report, Statistics of Railways of the U. S., 1905.

Dept. of Interior, U. S. Reclamation Service, fifth annual report, 1906. Cloth.

Dept. of Commerce and Labor, Washington, Bulletins 72, 73 and 76. Pams.

Dept. of Commerce and Labor, Bureau of Standards, Vol. 2, No. 3, Dec., '06.

U. S. War Dept. Washington,

Annual report, Chief of Engineers, 1906. Vol. 5. Cloth.

Annual report, Chief of Ordnance, 1906. Cloth.

Report of Tests and Metals, 1906. Cloth.

U. S. Patent Office, Specifications of various patents. 12 Pams.

Library of Congress, Select list of books relating to iron and steel in commerce. 1907. Pam.

U. S. Commission of Education, Washington. Report for the year 1905. Vols. 1 & 2. Cl.

Supt. of Documents, G. P. O. Catalogue of the U. S. Public Documents, May, 1907. Pam.

E. E. R. Tratman, M. W. S. E., Chicago. Water Supply and Irrigation Papers, Nos. 190-1-2-3-4-6 and 200. 7 Pams.

U. S. Geological Survey, Dept. of Int., Bul. 315, Economic Geology, 1906. Pam.

U. S. Dept. of Agriculture, Forest Service. Circular No. 36, June, 1907. Pam.

U. S. Dept. of Agriculture, Forest Service. Suggestions for Forest Planting in the Northeastern and Lake States, June, 1907. Circular 100. Pam.

U. S. Dept. of Agriculture, Forest Service. Circular No 106, June, 1907. Pams.

U. S. Geological Survey, Dept. of Int., Water Supply and Irrigation Papers. Nos. 190-1-2-3-4-6-200. 7 Pams.

U. S. Geological Survey, Dept. of Int. Nos. 287-94-96-300-8-12-14-15. Pam.

U. S. Geological Survey, Dept. of Int. Prof. paper 57—Geology of the Marysville Mining District, Mont.

U. S. Dept. of Agriculture, Forest Service. The use book.—Regulations and instructions for the use of the Natural Forests, July, 1907.

U. S. Dept. of Agriculture Forest Service. The open-tank method for the treatment of timber, July, 1907. Circular 101. Pam.

U. S. Dept. of Commerce and Labor, Bureau of the Census. Census of Manufacturers, 1905. Bul. 77. Lumber and Timber Products.

U. S. Dept. of Agriculture, Forest Service. Seasoning of telephone and telegraph poles. July, 1907. Circular No. 103. Pam.

U. S. Dept. of Agriculture, Forest Service. Circular 102. Production of Red Cedar for pencil wood, July, 1907. Pam.

U. S. Dept. of Agriculture, Forest Service. Circular 104. Brush and tank pole treatments, July, 1907. Pam.

Dept. of Commerce and Labor, Bureau of Census. Bul. 74. Census of Manufacturers' Textiles, 1905. Pam.

Dept. of Commerce and Labor, Bureau of Census. Manufacturers, 1905, Part 1, U. S. by Industries. Cl.

U. S. Dept. of Agriculture, Forest Service. The use of the National Forests, June, 1907. Cl.

U. S. Dept. of Agriculture, Forest Service. Suggestions for Forest Planting on the semi-arid plains. Circular 99. Pam.

EXCHANGES.

Engineering Association of New South Wales, Proceedings, 1905-6. Vol. 21. Cloth.

Chicago Board of Trade, 48th annual report, 1905. Cloth.

Institution of Civil Engineers, London, Proceedings, 1906-7, Part 1, 1907. Vol. CLXVII. Paper.

Institution of Electrical Engineers, London, Proceedings, January-February, 1907. Paper.

Institution of Electrical Engineers. Proc. Feb.-Mar., 1907. Vol. XXXVIII, Part 183. Pam.

Institution of Electrical Engineers, London, Journal. Part 184, Vol. XXXIX, July, 1907. Pam.

Institution of Mechanical Engineers, London, List of Members 1907; Articles and By-laws. Pam. President's address, 1907. Pam.

John Crerar Library, Chicago, Twelfth annual report for the year 1906.

Institution of Mechanical Engineers. Proc. Oct.-Dec., 1906. Pam.

Iron Age, New York. Iron Age Directory, 1907. Cloth.

New Jersey Sanitary Association. Proceedings, 32nd annual meeting, 1906.

American Railway Engineering and Maintenance of Way Ass'n, Bulletin No. 84, Feb., 1907. Economics of Railway Location. Pam.
Bulletin No. 86, Apr., 1907. Committee work for 1907-8. Pam.
Bulletins Nos. 87 and 88. Pams.

Brooklyn Engineers' Club, Brooklyn, N. Y. Proc. for 1906, List of Members, etc. Pam.

Engineers' Club of Philadelphia. List of Members, Charter and By-laws, 1907. Lea.

Chicago Academy of Science. Paleontology of the Niagaran Limestone in the Chicago Area. 2 Pams.

Chicago Academy of Science, Bul. IV, Part 2, Natural History Survey, May, 1907.

Chicago Academy of Science Birds of the Chicago Area. Bul. VI, Natural History Survey, April, 1907.

Conn. Society of Civil Engineers. Proceedings 23rd Annual Meeting, Feb., 1907. Pam.

University of Illinois, Urbana, Ill. Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Schmidt and Snodgrass April, 1907. Pam.

Royal Institution of Great Britain. Papers presented before the Institution, May 4-18-24. 3 Pams.

National Fire Protective Assn. Proc. of 11th Annual Convention, 1907.

Railway Signal Assn., Bethlehem, Pa. No. 3, Vol. X. Advance notice No. 4, meeting, September 10, 1907.

Ohio Engineering Society, Columbus, Ohio. Report of 28th Annual Meeting, 1907. Pam.

TRADE CATALOGUES.

National Electric Lamp Association, Cleveland, Ohio, Bul. No. 1 of Engineering Dept. Pam.

Glasgow Iron Co., Pottstown, Pa. Catalogue of flanged and pressed work. Cloth.

General Electric Co., Schenectady, N. Y. Various Bulletins from Supply Dept.

The B. F. Sturtevant Co., New York.
- Bul. 142. Generating Sets with Compound Engines.
- Bul. 143. Generating Sets with Horizontal Engines.
- Bul. 146. Electric Propeller Fans.

Chicago Portland Cement Co., Chicago, "AA" Chicago Portland Cement. Pam.

Ajax Line Material Co., Chicago. Catalogue No. 1, electric light specialties. Pam.

Sullivan Machinery Co., Chicago, Catalogue No. 55—Sullivan Diamond Drills, Pamphlet.

Jeffrey Mfg. Co., Columbus, Ohio, Jeffrey Coal and Ashes Handling Machinery for Power Plants. 2 Pams.

Abenaque Machine Works, Westminster Sta., Vermont, Abenaque Gas or Gasoline Driven, Direct Connected Air Compressor Outfits.

Fairbanks, Morse & Co., Chicago. Catalogue No. 114—Practical Irrigation. Pam.

Jeffrey Mfg. Co., Columbus, Ohio. Conveying machinery for Saw Mills, Lumber Mills and Wood-working Industries. Pam.

General Electric Co., Schnectady, N. Y. Catalogue of Fan Motors, 1907, and various Bulletins, 1907. Pamphlets.

Andrews Allen M. W. S. E., Chicago. "Steel Coal Tipples," 1907. Pam.

Franklin Filter Co., St. Louis, Mo. "Efficient Bearings." Pam.

National Electric Lamp Association, Cleveland, O. Various Bulletins regarding lamps. Pam.

American Spiral Pipe Works, Chicago. Forged and Rolled Steel Pipe Flanges, June, 1907. Pam.

Bausch, Lomb, Saegmuller Co., Rochester, N. Y. Astronomical and engineering instruments. May, 1907. Pam.

Chicago Bridge and Iron Works, Chicago. Catalogue of Metal Structures. Pam.

General Electric Co., Schenectady, N. Y. Various Bulletins. Pams.

General Electric Co., Schenectady, N. Y. Catalogue No. 7603. General Supplies. Cl.

Sullivan Machinery Co., Chicago. Bul. 56, Sullivan Mining Hoist, 1907. Pam.

BOOKS PURCHASED.

Barnes—Ice Formation, with special reference to anchor-ice and frazil.

Beardsley—Design and Construction of Hydro-electric Plants. 1907.

Damour—Industrial Furnaces and Methods of Control. 1906.

Fidler—Notes on Construction in Mild Steel. 1907.

Hoskins—A Text-book on Hydraulics, including an outline of the theory of turbines. 1906.

Leffler—The Elastic Arch, with special reference to the re-enforced Concrete arch. 1906.

Engineering Magazine, New York. Engineering Index Annual for 1906.

MEMBERSHIP.

Additions to Membership.

M. H. Dance, 1000, No. 1 Park Row, Chicago	Junior
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E. C. Hasselfield, 145 Seminary Avenue, Chicago, transferred from Junior to	Active
Samuel P. Hendricks, care Jas. Stewart & Co., New Orleans, La.	Junior
Henry K. Holsman, 663 Monadnock Block, Chicago	Active
Ralph C. Llewellyn, 1518 First Nat'l Bank Bldg., Chicago	Junior
J. S. McChesney, 859 W. Adams St., Chicago	Junior
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L. S. Richards, 3526 S. Paulina St., Chicago	Junior
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Corrected Addresses.

Anders, F. L., Pioche, Nevada.
Arneling, H. R., Miles City, Mont.
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Balsley, Eugene A., Mgr. Milwaukee plant, American Bridge Co., 17th St. and St. Paul Ave., Milwaukee, Wis.
Boardman, H. P., Prof. Civil Engineering, University Nevada, Reno, Nev.
Burgess, F. H., Monticello, Ill.
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Clayton, T. W., Shawneetown, Ill.
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Goodrich, H. C., Bingham, Utah.
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Hill, George S., 2717 Pacific Ave., San Francisco, Cal.
Jackson, W. B., R. 508 Commercial Bank Bldg., Chicago.
Kermer, Martin J., 409 E. Superior St., Chicago.
Krames, William, 4119 Windsor Ave., Kansas City, Mo.
Massa, R. F., 221 Ewing St., Chicago.
Mayer, George M., 416 Brady St., Elkhart, Ind.
Place, Floyd W., Lock 3 Sawyerville, Ala.
Porter, H. H. 1622 Tribune Bldg., Chicago.
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Slade, J. E., 1051 Georgia Ave., Omaha, Nebr.
Stewart, C. B., College of Engr'g, Univ. of Wis., Madison, Wis.
Walen, Jas. W., Plainville, Kan.
Wood, C. M., c/o The Kans. Gas Co., Independence, Kan.
Worthing, Eugene, 329 W. Third St., Cincinnati, Ohio.
Yale, F. W., Winfield, Kansas.

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THE PRESENT STATUS OF THE PRODUCER-GAS POWER PLANT IN THE UNITED STATES

By Robert Heywood Fernald,*

Presented May 1, 1907.

INTRODUCTORY.

Recent developments point very positively to two factors of great importance in the economical production of power for manufacturing and transportation purposes.

These two factors are the replacing to a marked extent of the steam boiler and steam engine by producer-gas plants with their accompanying internal combustion engines; and the centralization of power development and distribution.

So important is this economic production of power that the United States Government has taken an active interest in investigations of this problem. Within the past three years over $500,000 has been appropriated by Congress for carrying on the work of the United States Geological Survey Fuel Testing Plant, and at the last session of Congress an additional $250,000 was appropriated for the continuation of these fuel investigations during the fiscal year beginning July 1, 1907.

The work undertaken by this testing plant which includes besides the fuel testing department, a special department with its experts and funds for the testing of structural materials, has proved of such significance that President Roosevelt has taken an active hand in the formation of a national Advisory Board on Fuels and Structural Materials. This Board consists of representatives of the following organizations: American Institute of Mining Engineers, American Institute of Electrical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Institute of Architects, American Railway Engineering and Maintenance of Way Association, American Railway Master Mechanics' Association, American Foundrymen's Association, Association of American Portland Cement Manufacturers, Geological Society of America, Iron and Steel Institute, National Association of Cement Users, National Board of Fire Underwriters,

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* Professor of Mechanical Engineering, Washington University, St. Louis, Mo., and Engineer in Charge of Producer Gas Tests of the United States Geological Survey Fuel Testing Plant.

National Brick Manufacturers' Association, National Fire Protection Association, National Lumber Manufacturers' Association, Corps of Engineers United States Army, Isthmian Canal Commission, Bureau of Yards and Docks United States Navy, Supervising Architect's Office United States Treasury Department, and the Reclamation Service United States Interior Department.

The very intimate relation between this Government Fuel Testing Plant and many of the problems that concern the development of the gas producer and the producer-gas engine will be brought out later in this paper in more or less detail.

All data presented at this time and the general discussion of producer problems relate to the gas producer for power purposes only.

RAPID DEVELOPMENT OF THE GAS ENGINE.

It was during the latter part of the nineteenth century that the gas engine found its way on to the market, and, although many types have been produced in the past twenty or thirty years, it is only within the past five or six years that the development of large engines has been noted. This development started in Germany, Belgium, and England some eight or ten years ago, but marked progress has been limited to the past half-dozen years.

For many years the natural fuel of these internal combustion engines was city gas, but even this was too expensive except for engines of small capacity. It was seldom found feasible to operate engines of more than seventy-five horse power on this fuel.

Cheap gas was essential for the development of the gas engine, but the early attempts in this direction were somewhat discouraging, and for a time the probabilities of encroaching to any extent upon the field occupied by the steam engine was very remote.

The theoretical possibilities of the internal combustion engine operated upon cheap fuel promised so much that the practical difficulties were rapidly overcome with the result that steam boilers and engines in many plants were replaced by gas engines, and at the present time the internal combustion engine is rapidly becoming a serious rival of the steam engine in many of its applications.

The development of the gas engine in point of size has been exceedingly rapid. It was only seven years ago that a 600-horsepower engine exhibited at the Paris Exposition was regarded as a wonder, but today four-cycle, twin-tandem, double-acting engines run as high as 6,000 horse power.

DEVELOPMENT OF THE GAS PRODUCER.

This rapid advance of the large gas engine has been made possible by the great strides that have been made in the production of cheap gas directly from fuel through the aid of the gas-producer. The early form of producer first introduced in Europe, and one that is in very general use today both abroad and in the United States, is known as the suction producer, named from the fact that the engine develops its charge of gas in the producer by means of its own suction stroke. Although this type of producer is used very ex-

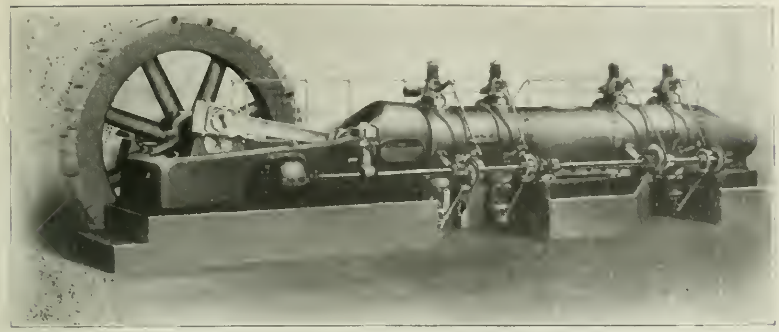


Fig. 1
Typical Horizontal Double Acting Gas Engine as Manufactured by the Westinghouse Machine Company.

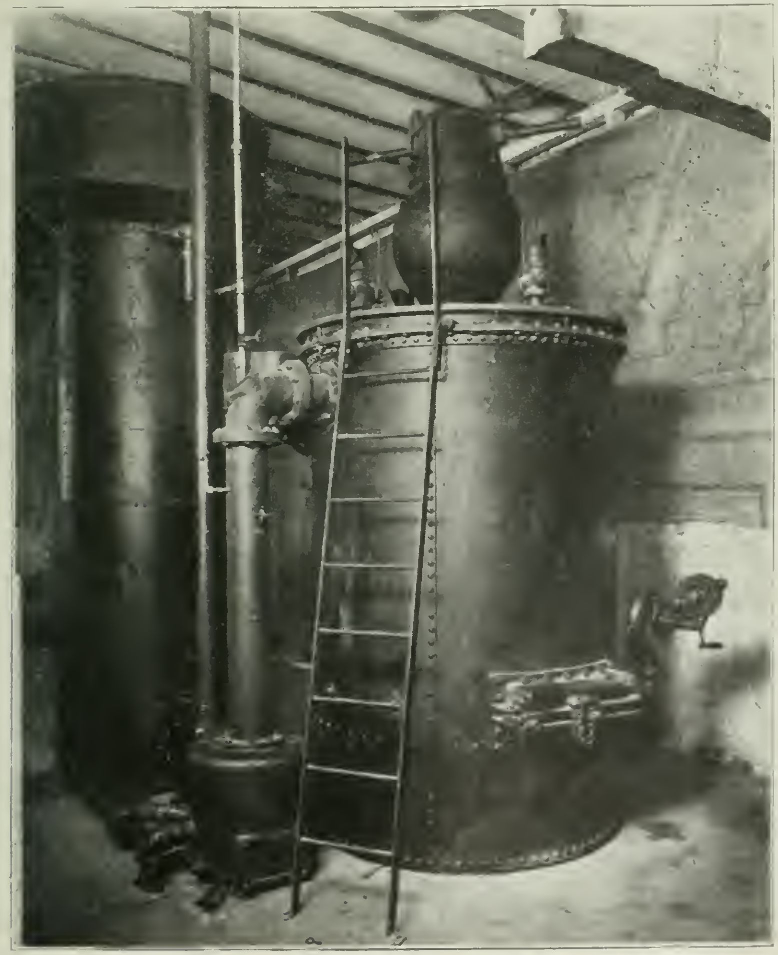


Fig. 2.
Typical Suction Gas Producer, Wile Power Gas Company.

tensively, its use is confined to small installations, usually not exceeding 150 horse power. As far as known the first suction producer operated in the United States was installed in Milford, New Hampshire, in 1903, although other types of producers were tried in this country as early as 1896. A serious limitation to this type of producer has been the fact that, owing to the manner of generating the gas, no tarry fuels could be used, thus barring bituminous coals, lignites, peats, etc. The fuels in most common use for suction producers are charcoal, coke, and anthracite coal, although attempts are being made to so construct suction plants that they can be operated on the bituminous, or tarry, coals.

In order to meet the demand for the concentration of power in large units, instead of operating a large number of engines of small power capacity, the pressure producer came into existence. This producer develops its gas under a slight pressure due to the introduction of an air and steam blast, and the gas is stored in a holder until such time as demanded by the engine. Owing to the fact that the gas may be stored in a tank before passing to the engine, and also since the gas is produced under pressure and does not depend on the suction of the engine for its generation, it is possible to introduce the necessary machinery for the removal of tar and other impurities from the gas thus opening the way to the use of bituminous coals and lignites. Following closely upon the pressure plants came the down-draft producers which fix the tar as a

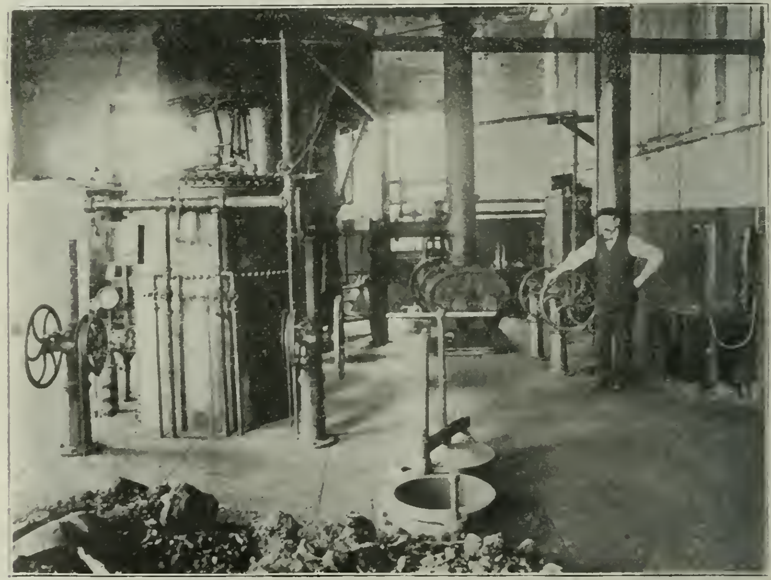


Fig. 3.

Typical Operating Floor of Down Draft Producer Installation as Manufactured by the Power & Mining Machinery Company.

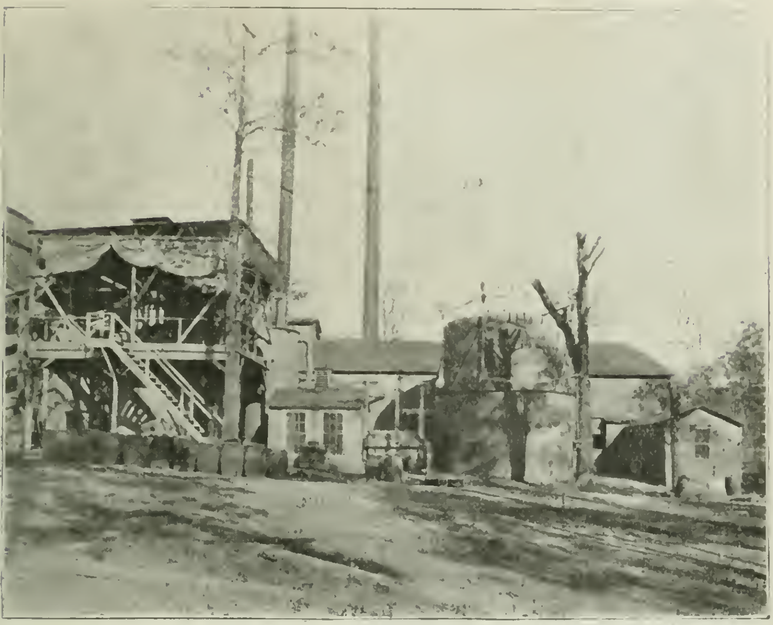


Fig. 4.
Pressure Producer Plant Manufactured by R. D. Wood & Co., in use at the United States Geological Survey Fuel Testing Plant.

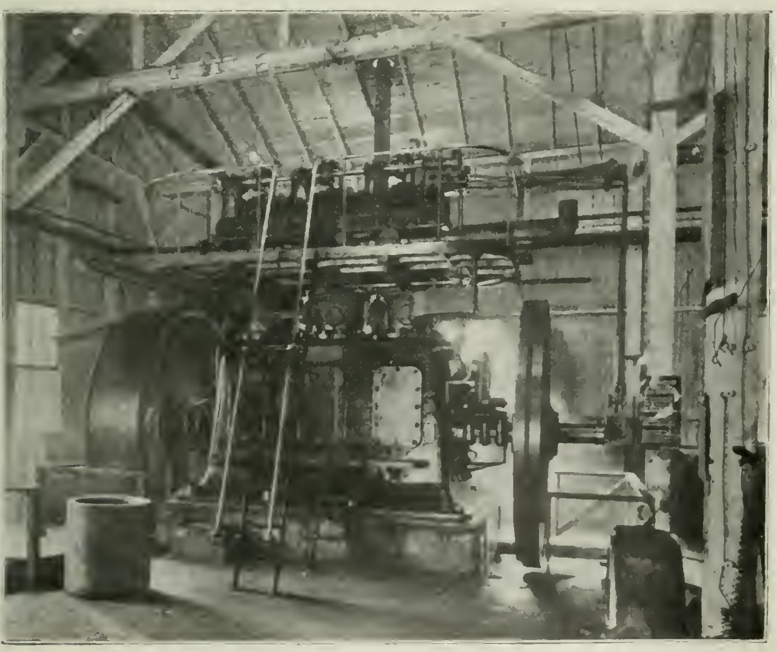


Fig. 5.
Three Cylinder Vertical Single Acting Westinghouse Gas Engine used at the United States Geological Survey Fuel Testing Plant.

permanent gas and can therefore use the bituminous coals and lignites.

These pressure and down-draft plants have been in operation for the past few years, but in most cases the fuel has been anthracite coal, although occasionally plants have ventured on the use of a few well-tried bituminous coals, known to be especially free from sulphur and low in ash and in tar production. It remained for the United States Geological Survey in its Testing Plant at Saint Louis to attempt the use of any and all bituminous coals, lignites, and peats, without reference to the amount of sulphur or tarry matter to be found in the fuel. It is gratifying to note that every coal received has been run through the producer and that the results have been more than satisfactory.

TESTS OF THE UNITED STATES GEOLOGICAL SURVEY.

So extremely important has this gas-engine, gas-producer problem become, with its possibility of driving out the steam engine in many large installations, that the Government made special provision for producer-gas tests at its Coal Testing Plant originally installed in connection with the Exposition at Saint Louis. These tests have resulted in furnishing very valuable data on the relative consumption of coal per horse power per hour when used by the steam plant and by the gas plant.

The steam plant upon which the tests were made consists of two 210-horse-power Heine boilers which furnished steam for a 250-horse-power, simple, non-condensing Corliss engine. This engine was belted to a Bullock electric generator.

The Producer-Gas Plant is a Taylor pressure gas producer furnished by R. D. Wood & Company, of Philadelphia. This producer designated as No. 7, is of 250-horse-power capacity. Together with the producer are the usual economizer, scrubber, tar extractor, purifier, and holder. (See Fig. 4.)

The Gas Engine installed is a three-cylinder, vertical, Westinghouse gas engine, with cylinders 19-inch diameter and 22-inch stroke, rated at 235 brake horse power on producer gas. (See Fig. 5.) The engine was belted to a six-pole 175 kilowatt Westinghouse direct current generator. The load on the generator was controlled by, and the energy developed dissipated through, a water rheostat especially constructed for the purpose.

Before discussing in detail the relative results from the steam and gas plants, some of the most important items connected with the producer-gas work are presented.

Since the installation of this plant in 1904 one hundred and sixty-two producer-gas tests were made, prior to moving the plant to the Jamestown Exposition, Norfolk, Va., in March, 1907. The fuels used have been bituminous coals, lignites, and peats from twenty-six different states, as indicated below:

BITUMINOUS COALS TESTED:

	No. from each State	
Alabama	3	
Arkansas	2	
Illinois	29	
Indiana	15	
Indian Territory	2	
Iowa	1	
Kansas	2	
Kentucky	5	
Missouri	1	
New Mexico	3	
Ohio	10	
Pennsylvania	13	
Tennesee	8	
Utah	1	
Virginia	5	
Washington	1	
West Virginia	14	
Wyoming	5	120

LIGNITES TESTED:

Arkansas	1	
California	1	
Colorado	1	
Montana	3	
North Dakota	4	
Texas	4	
Washington	3	
Wyoming	1	18
		138

MISCELLANEOUS FUELS TESTED:

	No. from each State	
Forward		138
Argentine	1	
Brazil	1	
California and Cinders	2	
Florida Peat	1	
Massachusetts Peat	1	
Rhode Island Anthracite	1	
Virginia Pea Anthracite	1	
Coke Breeze	1	
Miscellaneous Refuse	1	
Coke	1	11

DUPLICATE TESTS.

Coal:

Illinois	2	
Indiana	4	
Kansas	1	
Ohio	1	
Pennsylvania	2	
Tennessee	1	
West Virginia	1	12

Lignites:

North Dakota	1	1
Total tests made		162

Table I.

		Bituminous Coals.						Lignites						*Peat	
		As fired.			Dry.			As fired			Dry			As fired	Dry
		Ave.	Max	Min.	Ave.	Max.	Min.	Ave	Max.	Min	Ave	Max.	Min		
90 to 100% load	30 to 50 hrs. BTU per lb.	(127) 12280	14674	8735	(127) 13150	15073	10489	(18) 8350	10685	6970	(18) 11290	11686	10321	8127	10289
	Cu ft. of Gas per lb.	(85) 60.5	100.8	32.0	(85) 64.70	103.50	40.90	(7) 35.80	45.90	26.10	(7) 45.70	52.80	38.80	30.80	38.30
	Lbs. per sq ft of Fuel-bed per hr.	(93) 7.54	11.84	4.67	(95) 7.13	10.44	4.56	(10) 12.30	14.79	8.46	(10) 9.13	12.22	7.56	15.20	12.0
	Total lbs per B.H.P. hr.	(92) 1.36	2.05	0.84	(98) 1.26	1.81	0.82	(10) 1.99	2.75	1.48	(10) 1.83	2.02	1.35	2.57	2.08

		Bitum. Coals			Lignites.			*Peat
		Ave	Max.	Min.	Ave.	Max.	Min.	
BTU per cu ft of Standard Gas.		(124) 152.1	176	126.6	(18) 158.4	188.5	125.3	175.2
BTU per B.H.P. hr. Full Load		(89) 11300	12514	9510	(7) 11081	11810	9700	12840
Lbs of Tar per Ton of Fuel as Fired	Water not extracted	(43) 3308	745	130	(9) 175.	289	66	—
	Water extracted	(14) 316	624	92	(1) 110	110	110	—
Composition of Fuel. per cent		(130)			(18)			
Moisture		6.83	16.69	1.43	26.60	39.56	8.51	21.0
Volatile Combustible.		3306	4246	970	3140	38.41	2564	5172
Fixed Carbon		4980	7370	3119	32.60	45.69	23.80	22.11
Ash		1032	2344	2.77	953	15.47	2.74	5.17
Sulphur		2.41	*736	028	129	4.88	047	445
Composition of Gas. Vol. per cent		(130)			(18)			
Carbon Dioxide	CO_2	9.84			10.55			12.40
Oxygen	O_2	0.04			0.16			0.0
Ethylene	C_2H_4	0.18			0.17			0.4
Carbon Monoxide	CO	18.28	23.89	11.93	18.72	25.20	13.90	21.0
Hydrogen	H_2	12.90	18.60	2.81	13.74	19.30	9.20	18.50
Methane	CH_4	3.12			3.44			2.80
Nitrogen	N_2	55.60			53.22			45.5

Remarks

* A mixture of California lignite and cinders contained 8.1 per cent Sulphur.

Figures in circles indicate number of tests averaged. Thus (20)

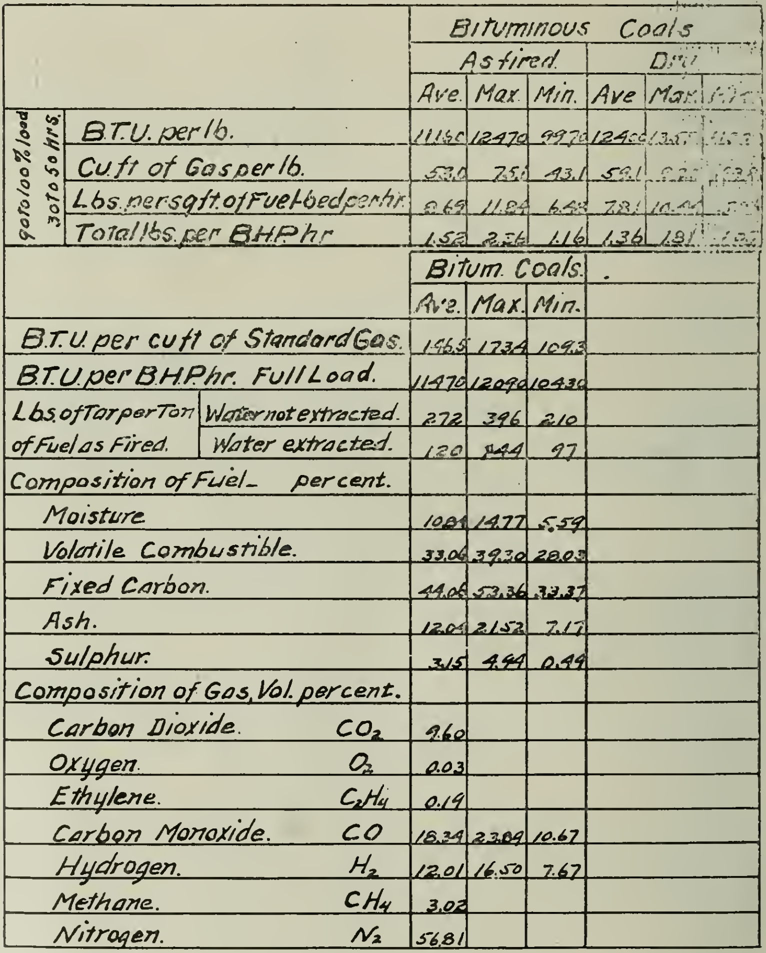
*1 sample of peat only.

In Table I is presented a condensed summary of the most important items relating to the coals and lignites tested in the gas-producer. The figures are also presented for Florida peat, although but one sample was received. It should be noted that all items in this table which are affected by the load factor are given only for loads ranging from 90 to 100 per cent of full load (235 B. H. P. in case of this plant).

In the same manner Table II gives the data derived from the Illinois coals tested.

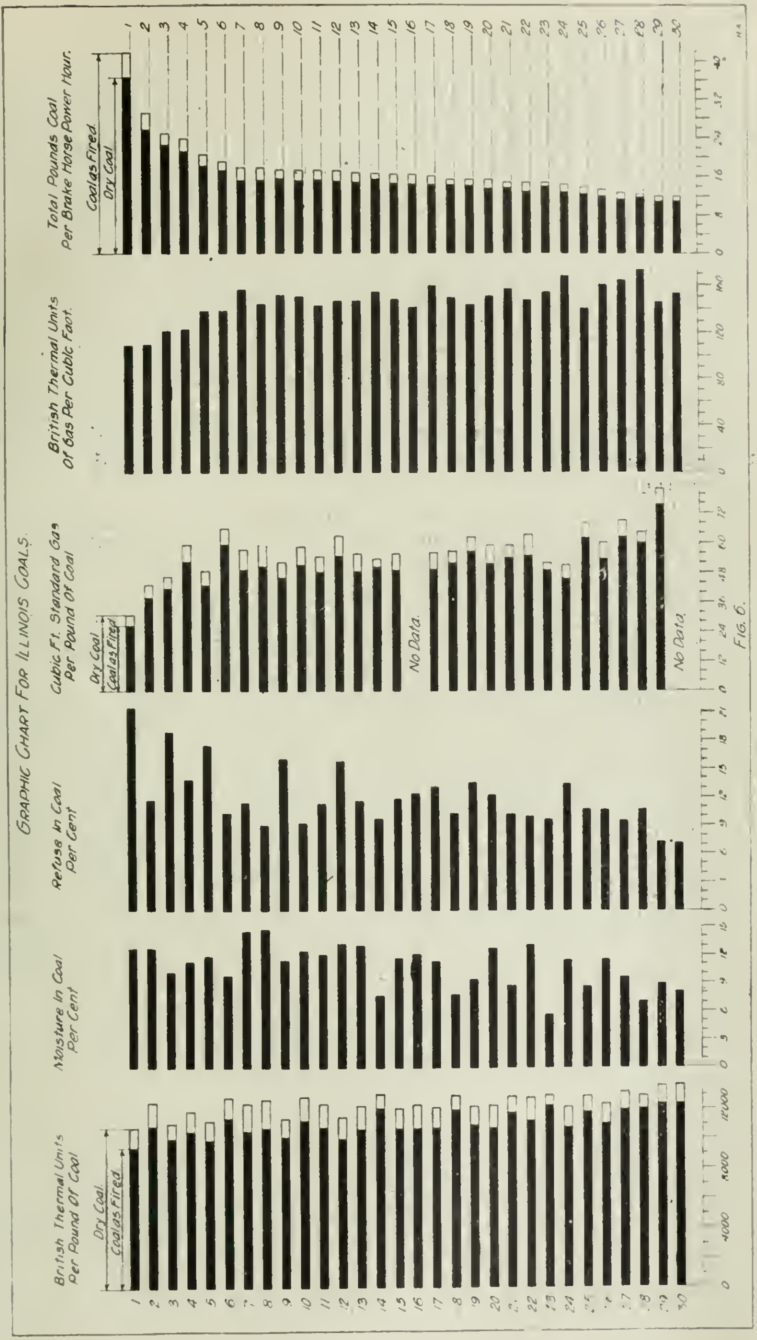
The graphic chart, Fig. 6, shows several of the results from the individual Illinois coals. A brief description of each coal follows the chart.

Table II.



		Bituminous Coals					
		As fired.			Dry		
		Ave.	Max.	Min.	Ave	Max.	[illegible]
90 to 100% load	30 to 50 hrs. B.T.U. per lb.	11150	12470	9970	12400	[illegible]	[illegible]
	Cu ft of Gas per lb.	53.0	75.1	43.1	59.1	[illegible]	[illegible]
	Lbs. per sq ft. of Fuel-bed per hr.	8.69	11.84	6.48	7.81	[illegible]	[illegible]
	Total lbs. per B.H.P. hr.	1.52	2.56	1.16	1.36	1.81	[illegible]

		Bitum. Coals.			
		Ave.	Max.	Min.	
B.T.U. per cu ft of Standard Gas.		146.5	173.4	109.3	
B.T.U. per B.H.P. hr. Full Load.		11470	12090	10430	
Lbs. of Tar per Ton of Fuel as Fired.	Water not extracted.	272	396	210	
	Water extracted.	120	144	97	
Composition of Fuel— per cent.					
Moisture		10.84	14.77	5.59	
Volatile Combustible.		33.06	39.30	28.03	
Fixed Carbon.		44.08	53.36	33.37	
Ash.		12.04	21.52	7.17	
Sulphur.		3.15	4.44	0.44	
Composition of Gas, Vol. per cent.					
Carbon Dioxide.	CO_2	9.60			
Oxygen.	O_2	0.03			
Ethylene.	C_2H_4	0.19			
Carbon Monoxide.	CO	18.34	23.09	10.67	
Hydrogen.	H_2	12.01	16.50	7.67	
Methane.	CH_4	3.02			
Nitrogen.	N_2	56.81			



GRAPHIC CHART FOR ILLINOIS COALS.

FIG. 6.

BRIEF DESCRIPTION OF ILLINOIS COALS.

(Numbers correspond to those in preceding chart.)

1. Illinois 7-A. Bituminous coal from mine No. 2, Lumaghi Coal Co., near Collinsville, Madison County, Ill., on the Vandalia R. R. Size as shipped, slack. Size as used, not determined.

2. Illinois 11-C. Bituminous coal from Daw's shaft, St.. Louis Big Muddy Coal Co., near Carterville, Williamson County, Ill., on the Illinois Central R. R. This coal was made up for testing from two washed samples.

3. Illinois 7-C. Bituminous coal from mine No. 2, Lumaghi Coal Co., near Collinsville, Madison County, Ill., on the Vandalia R. R. Size as shipped, slack. Size as used, not determined.

4. Bituminous coal from the mine of the Auburn-Alton Coal Co., located at Auburn, Sangamon County, Illinois, on the Chicago & Alton R. R. Size as shipped, run of mine. Size as used, same.

5. Illinois 7-B. From same mine as coals mentioned in 1, and 3. This sample consisted of nut coal which had passed over a 1-inch screen.

6. Illinois 19-C. Bituminous coal from mine of Ziegler Coal Co., Zeigler, Franklin County, Ill., on the Illinois Central R. R. Size as shipped, run of mine.

7. Illinois 21. Bituminous coal from No. 3 mine of the Donk Bros. Coal & Coke Co., located at Troy, Madison County, Ill., on the St. Louis, Troy, & Eastern R. R. Size as shipped, lump over a 2½-inch screen. Size as used, not determined.

8. Illinois 23-B. Bituminous coal from mine No. 1 of Donk Bros., Coal & Coke Co., located at Donkville, Madison County, Ill., on the St. Louis, Troy & Eastern R. R. Size as shipped. slack through a 2-inch perforated screen. Size as used, slack.

9. Illinois 6-B. Bituminous coal from Coffeen mine, Clover Leaf Coal Co., Coffeen, Montgomery County, Ill., on the Toledo, St. Louis & Western R. R. Size as shipped, run of mine. Size as used, not determined.

10. Illinois 4. Bituminous coal from mine No. 3 of the Donk Bros. Coal & Coke Co., Troy, Ill., on St. Louis, Troy & Eastern R. R. Size as shipped, over two-inch screen. Size as used, not determined.

11. Illinois 9-B. Bituminous coal from mine No. 2, Mt. Olive & Staunton Coal Co., Staunton, Macoupin County, Ill., on the Litchfield & Madison Ry. Size as shipped, lump. Size as used, not determined.

12. Illinois 26. Bituminous coal from the Lincoln mine of the Latham Coal Co., Lincoln, Logan County. Ill., on the Chicago & Alton R. R. Size as shipped, run of mine. Size as used, same.

13. Illinois No. 8. Bituminous coal from Paisley mine, Dering Coal Co., Paisley, Montgomery County, Ill., on the Cleveland Cincinnati, Chicago & St. Louis Ry. Size as shipped, nut. Size as used, not determined.

14. Illinois No. 3. Bituminous coal from mine No. 3, South-

ern Illinois Coal Mining & Washing Co., Marion, Williamson County, Ill., on the Chicago & Eastern Illinois R. R. Size as shipped, run of mine. Size as used, not determined.

15. Illinois 23-A. Bituminous coal from mine No. 1, Donk Brothers Coal & Coke Co., Donkville, Madison County, Ill., on the St. Louis, Troy & Eastern R. R. Size as shipped, "Superior lump," over a 5-inch screen. Size as used, same.

16. Illinois 29-B. Bituminous coal from mine of New Staunton Coal Co., Livingston, Madison County, Ill., on the Chicago & Eastern Illinois R. R., and Cleveland, Cincinnati, Chicago & St. Louis R. R. Size as shipped, run of mine.

17. Illinois 22-A. Bituminous coal from No. 2 mine of Donk Bros. Coal & Coke Co., Maryville, Madison County, Ill., on the St. Louis, Troy & Eastern R. R. Size as shipped, lump over a 4-inch perforated shaker screen. Size as used, same.

18. Illinois 16. Bituminous coal from mine No. 7 Big Muddy Coal and Iron Co., Herrin, Williamson County, Ill., on the Illinois Central R. R. Size as shipped, lump and egg. Size as used, not determined.

19. Illinois No. 15. Bituminous coal from south mine of Pettinger & Davis, Centralia, Marion County, Ill., on the Illinois Central R. R. Size as shipped, lump and egg. Size as used, not determined.

20. Illinois 14. Bituminous coal from No. 2 mine, Capital Coal Co., east side of Springfield, Sangamon County, Ill., on the Illinois Central R. R. Size as shipped, lump. Size as used, not determined.

21. Illinois 13. Bituminous coal from Benton mine, Benton Coal Co., Benton, Franklin County, Ill., on the Chicago & Eastern Illinois R. R. Size as shipped, 1½ to 6-inch egg. Size as used, not determined.

22. Illinois 18. Bituminous coal from La Salle shaft mine, La Salle County Carbon Coal Co., La Salle, Ill., on the Illinois Central R. R. Size as shipped, lump. Size as used, not determined.

23. Illinois 30. Bituminous coal from mine of Southern Coal & Mining Co., Shiloh, Saint Clair County, Ill., on the Southern Ry. Size as shipped, washed coal.

24. Illinois 25. Bituminous coal from No. 10 mine of the Southern Coal & Mining Co., one half mile east of Germantown, Clinton County, Ill., on the Southern Ry. Size as shipped, lump. Size as used, same.

25. Illinois 10. Bituminous coal from West Frankfort mine, Dering Coal Co., West Frankfort, Franklin County, Ill., on the Chicago & Eastern Illinois R. R. Size as shipped, slack. Size as used, not determined.

26. Illinois 24-B. Bituminous coal from mine No. 9, of the Southern Coal & Mining Co., New Baden, Clinton County,

Ill., on the Southern Ry. Size as shipped, lump over a 5½-inch bar screen. Size as used, same.

27. Illinois 19-B. Bituminous coal from Zeigler mine, Zeigler Coal Co., Zeigler, Franklin County, Ill., on the Illinois Central R. R. Size as shipped, lump. 3-inch. Size as used, over 1 inch, 77 per cent.; ½-inch to 1 inch, 9 per cent.; ¼ inch to ½ inch, 5 per cent.; under ¼ inch 9 per cent.

28. Illinois 11-A. Bituminous coal from Daw's shaft, St. Louis & Big Muddy Coal Co., near Carterville, Williamson County, Ill., on the Illinois Central R. R. Size as shipped, egg. Size as used, not determined.

29 & 30. Illinois 11-D. From same mine as No. 28. Size as shipped, run-of-mine, washed. Size as used, not determined.

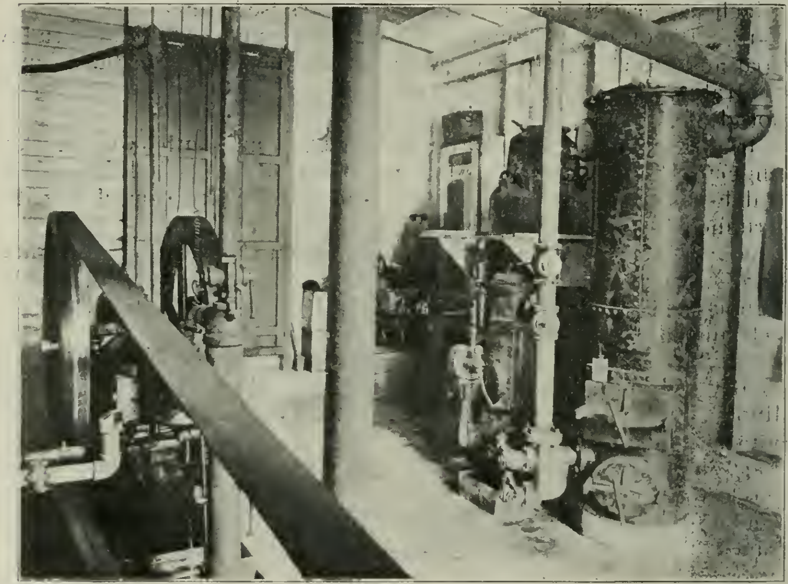


Fig. 7

Suction Producer Gas Power Installation by the Otto Gas Engine Works.

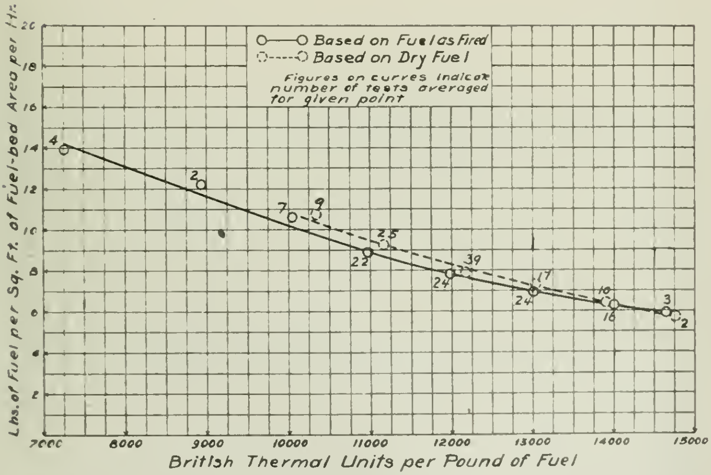
In presenting the accompanying charts too much emphasis cannot be given to the fact that the tests from which these curves were deduced have been subjected to absolutely no refinements. With the possible exception of two or three coals, one test only has been made on each fuel, and the result of each test has, to a great extent, depended upon the ability of the producer operator to "catch on" to the methods of handling a given coal within the eight or ten hours allowed preliminary to the official test.

To illustrate, tests Nos. 71 to 74 inclusive, taken in consecutive order, were upon coals from Pennsylvania, North Dakota, Ohio, and Virginia.

It should also be borne in mind that all the tests have been made on one type and in one size of producer—a type designed primarily for anthracite coal—and that it has been imperative that the test be made and the required power generated without regard to the proper relations between the gas producing qualities of the coal and the fuel bed area.

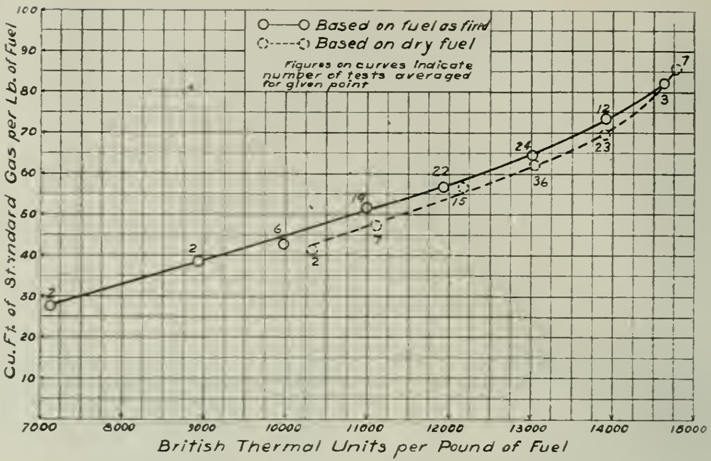
The restrictions have been such that the tests have been conducted on the basis of steady load on the engine (235 brake horse power) and not on the basis of maximum power producing quality of the coal.

In spite of these restricted conditions, the general conclusions are regarded as sufficiently significant for presentation although subject to modification in the light of later investigations. They are accordingly indicated in the following diagrams:



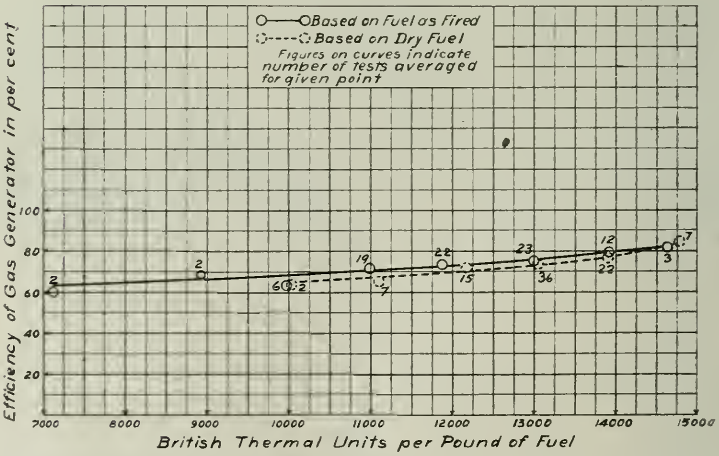
RESULTS FROM 93 BITUMINOUS COALS AND 9 LIGNITES AT FULL LOAD

Fig. 8.



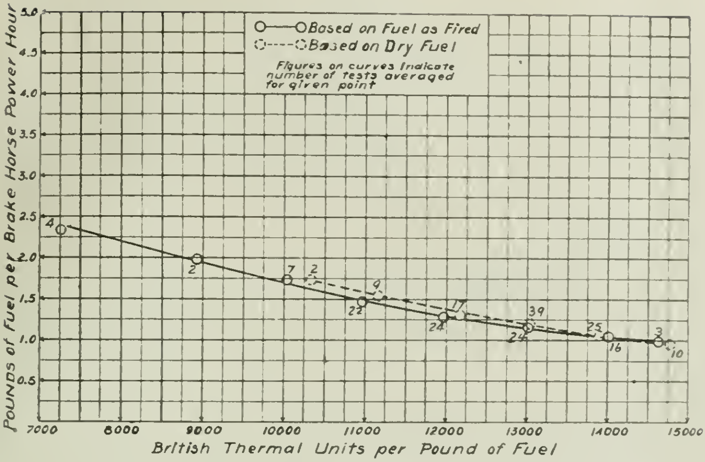
RESULTS FROM 84 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD

Fig. 9.



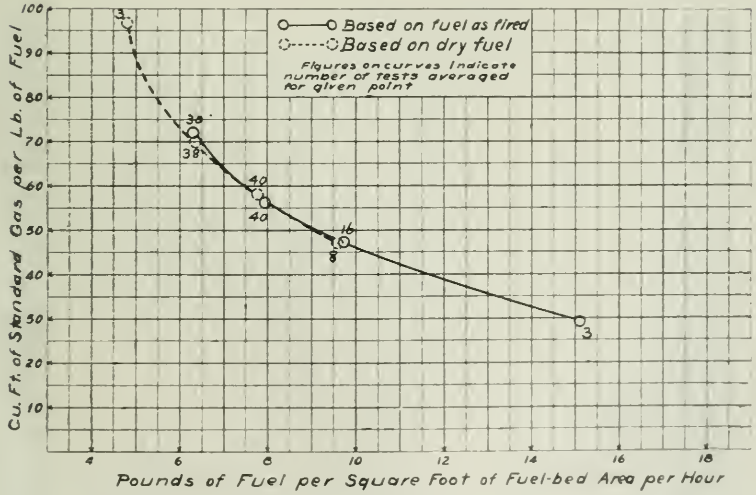
RESULTS FROM 83 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD

Fig. 10.



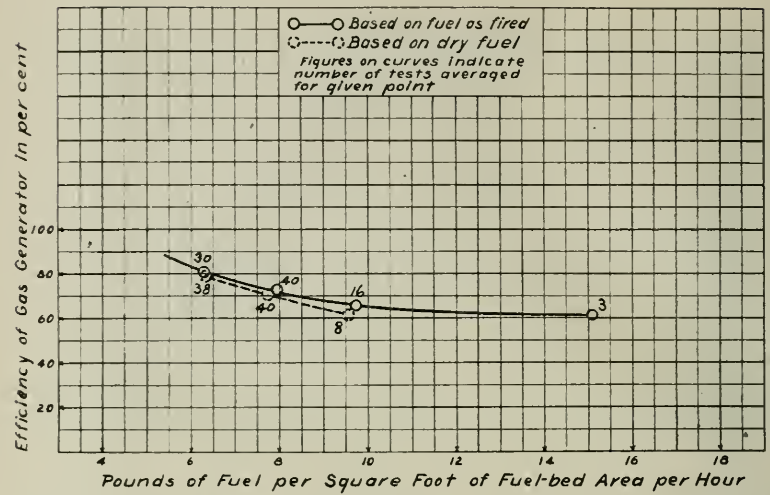
RESULTS FROM 93 BITUMINOUS COALS AND 9 LIGNITES AT FULL LOAD

Fig. 11.



RESULTS FROM 83 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD

Fig. 12.



RESULTS FROM 83 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD

Fig. 13.

RELATIVE RESULTS OF STEAM AND PRODUCER-GAS TESTS.

In considering the relation between the economic results of the two types of plants under discussion, viz.—steam and producer-gas, attention is called to the fact that today in the ordinary manufacturing plant operated by steam power less than 5 per cent. of the total energy in the fuel consumed is available for useful work at the machine.

Before examining the figures from the Government Testing Plant, it is of interest and value to glance at the possibilities of the best designed and most skillfully operated plants commercially in use today. The data of the steam plant selected for this comparison are from the table prepared by Mr. Stott, Superintendent of Motive Power, Interborough Rapid Transit Company, New York City, and of which Mr. Stott says*, "In Table 1 will be found a complete analysis of the losses found in a year's operation of what is probably one of the most efficient plants in existence today and, therefore, typical of the present state of the art."

Mr. Stott says further regarding the thermal efficiency of producer-gas power plants:

"The following heat balance is believed to represent the best results obtained in Europe and the United States up to date in the formation and utilization of producer gas.

---

* See Transactions A. I. E. E., 1906, Power Plant Economics, by Henry G. Stott.

OF ONE

per cent.
20.
19.
30.
6.5
0.5
76.0
24.
100.0

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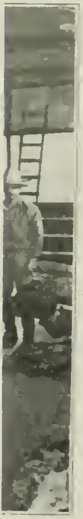


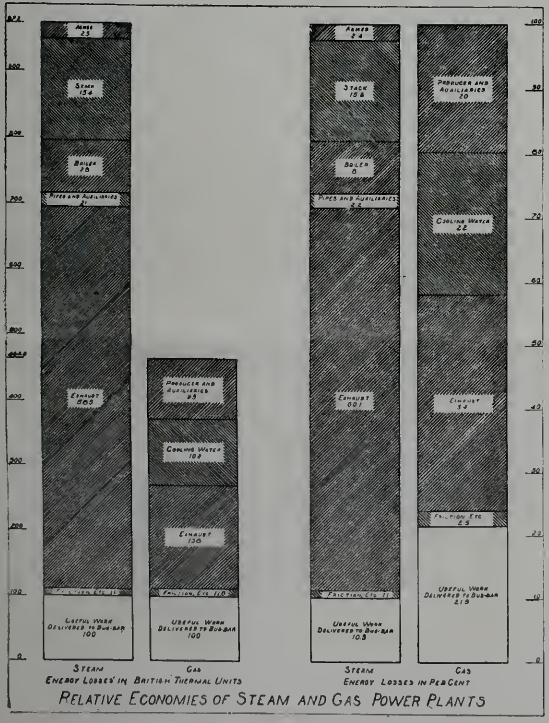

972
900
800
700
600
500
466
400
300
200
100
0
Ashes 25
Stack 154
Boiler 78
Pipes and Auxiliaries 21
Exhaust 583
Friction, Etc 11
Useful Work Delivered to Bus-bar 100
Producer and Auxiliaries 123
Cooling Water 102
Exhaust 130
Friction, Etc 11.0
Useful Work Delivered to Bus-bar 100
Steam
Gas
Energy Losses in British Thermal Units
Ashes 2.4
Stack 15.8
Boiler 8
Pipes and Auxiliaries 2.2
Exhaust 60.1
Friction, Etc 1.1
Useful Work Delivered to Bus-bar 10.3
Producer and Auxiliaries 20
Cooling Water 22
Exhaust 34
Friction, Etc 2.5
Useful Work Delivered to Bus-bar 21.5
Steam
Gas
Energy Losses in Per Cent
100
90
80
70
60
50
40
30
20
10
0
Relative Economies of Steam and Gas Power Plants

Fig. 15.

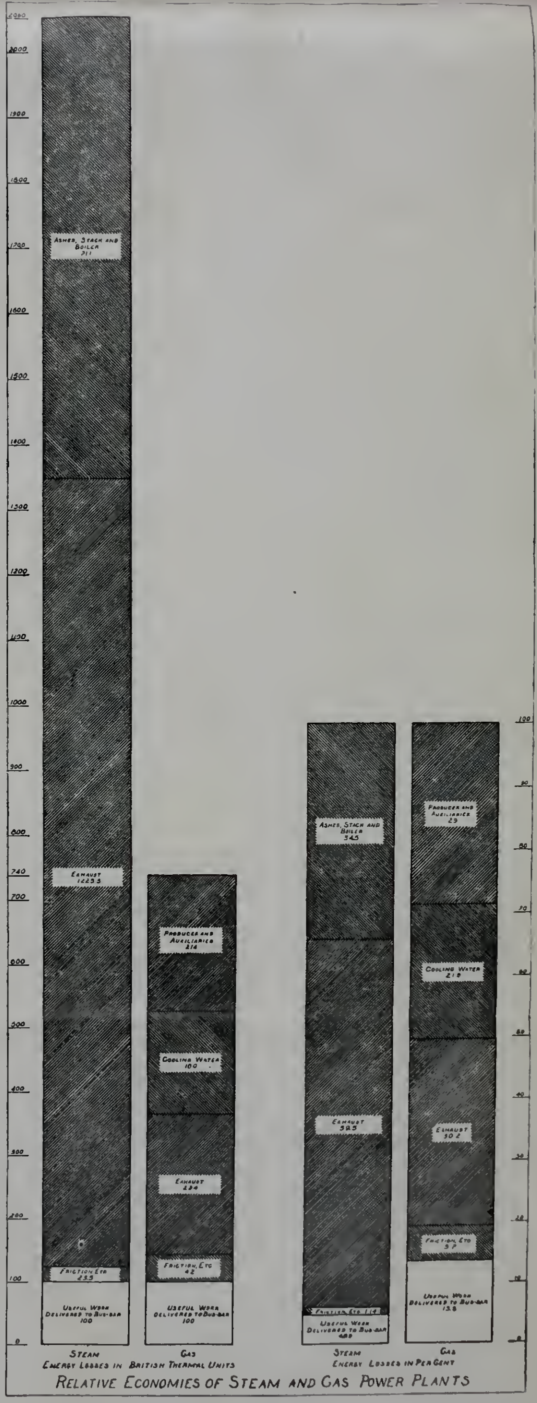

2058
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
740
700
600
500
400
300
200
100
0
Ashes, Stack and Boiler 711
Exhaust 1223.5
Friction Etc 23.5
Useful Work Delivered to Bus-bar 100
Producer and Auxiliaries 214
Cooling Water 100
Exhaust 284
Friction, Etc 42
Useful Work Delivered to Bus-bar 100
Steam
Gas
Energy Losses in British Thermal Units
Ashes, Stack and Boiler 34.5
Exhaust 59.5
Friction, Etc 1.1
Useful Work Delivered to Bus-bar 4.9
Producer and Auxiliaries 29
Cooling Water 21.8
Exhaust 30.2
Friction, Etc 5.2
Useful Work Delivered to Bus-bar 13.8
Steam
Gas
Energy Losses in Per Cent
100
90
80
70
60
50
40
30
20
10
0
Relative Economies of Steam and Gas Power Plants

Fig. 16

ANALYSIS OF THE AVERAGE LOSSES IN THE CONVERSION OF ONE POUND OF COAL CONTAINING 12,500 B. t. u. INTO ELECTRICITY.

		B. t. u.	per cent.
1.	Loss in gas producer and auxiliaries.....	2,500	20.
2.	Loss in cooling water in jackets.........	2,375	19.
3.	Loss in exhaust gases.................	3,750	30.
4.	Loss in engine friction..................	813	6.5
5.	Loss in electric generator.............	62	0.5
6.	Total losses	9,500	76.0
7.	Converted into electric energy..........	3,000	24.
		12,500	100.0

The figures for the thermal efficiency of such plants given by different writers run as high as 33, 36, 38.5 per cent. and in some cases figures as wild as "above 40" are boldly published.

Although the present aim has been to present figures for a producer-gas plant that may compare favorably with those of the steam plant mentioned, an effort has been made to keep well within conservative efficiencies. Attention is also directed to the fact that the producer-gas plant considered should be of such size as to compare favorably with the steam plant. This precludes the suction plants, which are of relatively small size, but which give higher thermal plant-efficiencies than the larger pressure and down-draft plants which require more or less auxiliary apparatus

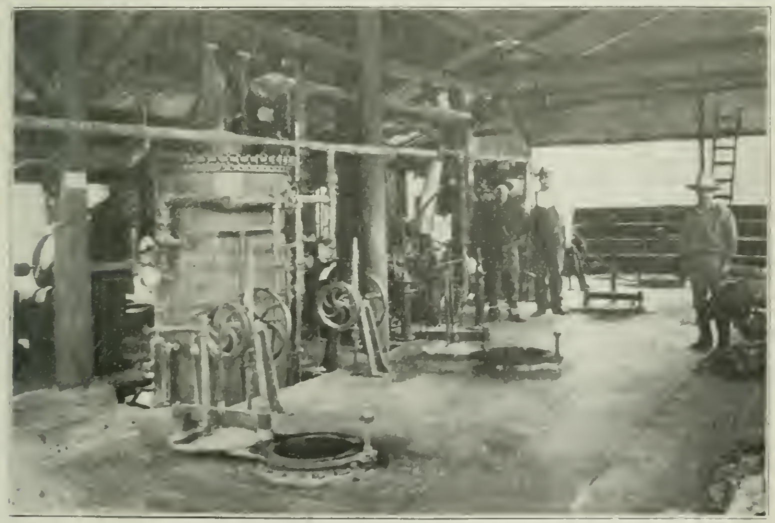


Fig. 14.
Loomis-Pettibone Installation Using Wood for Fuel

Although Mr. Stott seems ready to accept a thermal efficiency for the best producer-gas plants of 24 per cent. as the proper figure for comparison with his steam plant of 10.3 per cent. efficiency, a careful study of the problem has led to the use of a more conservative figure, viz., 21.5 per cent., for the producer-gas plant in constructing the diagram shown in Fig. 15.

Fig. 16 presents in the same graphic manner the average relative thermal efficiencies of the steam and producer-gas plants at the Government Testing Station.

At the left of each of these figures is shown the number of British thermal units that must be delivered to the furnace or producer in the fuel of the steam and gas plants respectively in order that 100 British thermal units may be converted into electrical energy. At the right is shown the percentage of useful work at the bus bars for the plants considered.

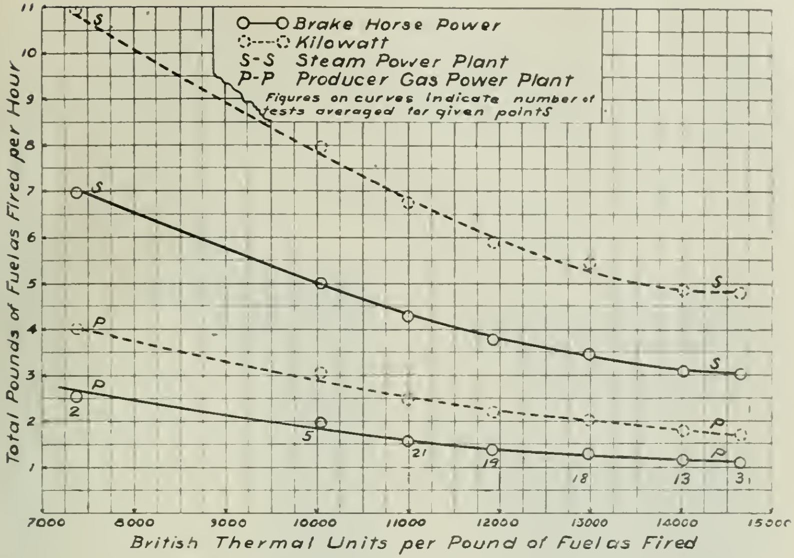
The curves in Figs. 17 and 18 show the great economy secured from seventy-five bituminous coals and six lignites when used in the gas producer instead of under the steam boiler. The results of the tests are officially reported on the basis of switchboard horse power, but in order that they may be of more practical value they are given here on the basis of brake horse power and kilowatt—the efficiency of electric generator and belt in each plant being assumed as 85 per cent.

Especial attention should be called to the fact that several low grade coals and lignites which have proved of little value or even worthless under the steam boiler have given excellent returns in the gas producer.

The ratios of the total fuel per brake horse power hour required by the steam plant and producer-gas plant under full load conditions, not counting stand-by losses, are presented below as derived from 75 coals, 6 lignites, and 1 peat (Florida).

Average ratio. coal as fired per b. h. p. hr. (under boiler) to coal as fired per b. h. p. hr. producer	2.7
Maximum ratio, coal as fired per b. h. p. hr. under boiler to coal as fired per b. h. p. hr. in producer	3.7
Minimum ratio, coal as fired per b. h. p. hr. under boiler to coal as fired per b. h. p. hr. in producer	1.8
Average ratio, lignite as fired per b. h. p. hr. under boiler to lignite as fired per b. h. p. hr. in producer	2.7
Maximum ratio. lignite as fired per b. h. p. hr. under boiler to lignite as fired per b. h. p. hr. in producer	2.9
Minimum ratio. lignite as fired per b. h. p. hr. under boiler to lignite as fired per b. h. p. hr. in producer	2.2
Average ratio peat as fired per b. h. p. hr. under boiler to peat as fired per b. h. p. hr. in producer	2.3

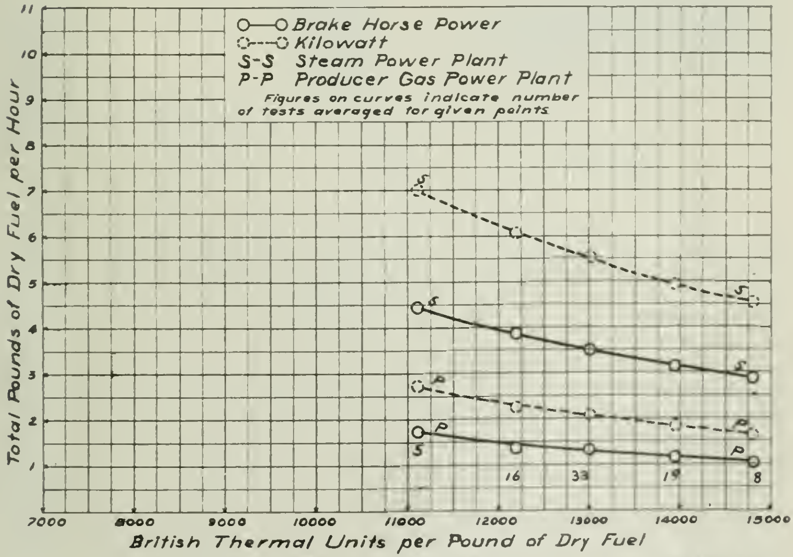
In case of the results for the producer gas tests the figures include not only the coal consumed in the gas generator but also the coal used in the auxiliary boiler for generating the steam necessary



75 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD (235 B.H.P.)

—— COMPARATIVE POWER PLANT DUTY ——

Fig. 17.



75 BITUMINOUS COALS AND 6 LIGNITES AT FULL LOAD (235 B.H.P.)

—— COMPARATIVE POWER PLANT DUTY ——

Fig. 18.

for the pressure blast, i. e., the figures given include the *total* coal required by the gas producer plant.

This ratio for the Illinois coals is shown graphically for each coal in Fig. 19, the average ratio being 2.6. As indicated by the chart no steaming tests were made on some of these coals.

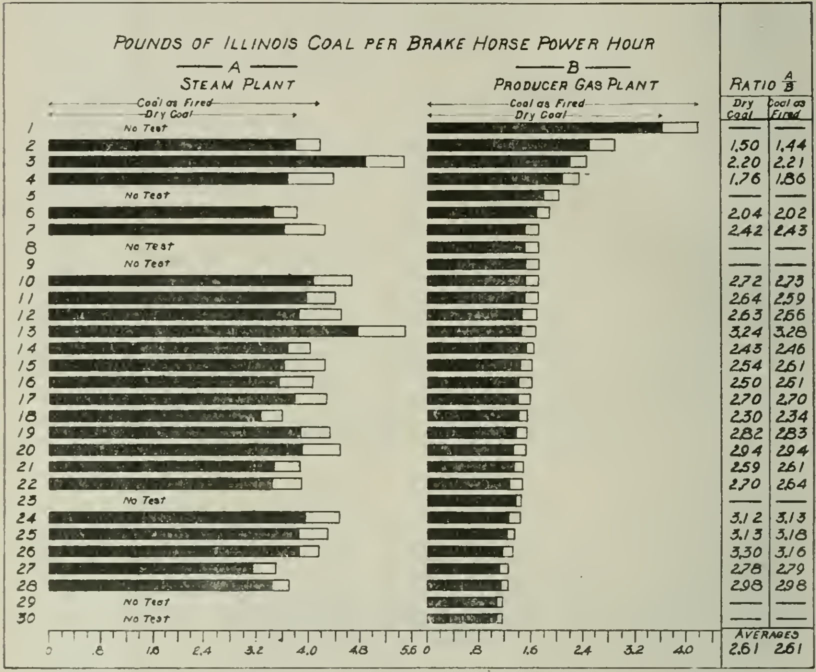


Fig. 19

In the above comparisons between the steam and producer gas plants no consideration has been made of stand-by losses. Each plant has been considered on the basis of continuous operation during a given period. Data upon stand-by losses for plants operated during a portion of each 24-hour day are not at present obtainable from the Fuel Testing Plant. There seems to be little of value published relating to this point and opinions regarding the amount of fuel required for holding fires over night or during idle periods in both boiler and producer plants seem to differ widely.

It is probable that the most reliable figures obtainable today relating to this point are those presented by Messrs. Dowson & Larter in their recent book entitled Producer Gas. The results secured by these gentlemen from a number of engineers and experimenters, including such well-known names as that of Mr. Bryan Donkin, indicate that for plants of about 250 H. P. the stand-by losses amount to about 67 pounds of coal per standing hour for the steam plant and to about 4 pounds per standing hour for the producer-gas plant.

On the basis of these figures the chart shown in Fig. 20 has been prepared for steam and producer-gas plants of 235 b. h. p. operating ten hours a day. The figures for coal consumption during the period of operation are those obtained at the Fuel Testing Plant at St. Louis, and the figures for stand-by losses are from the source indicated.

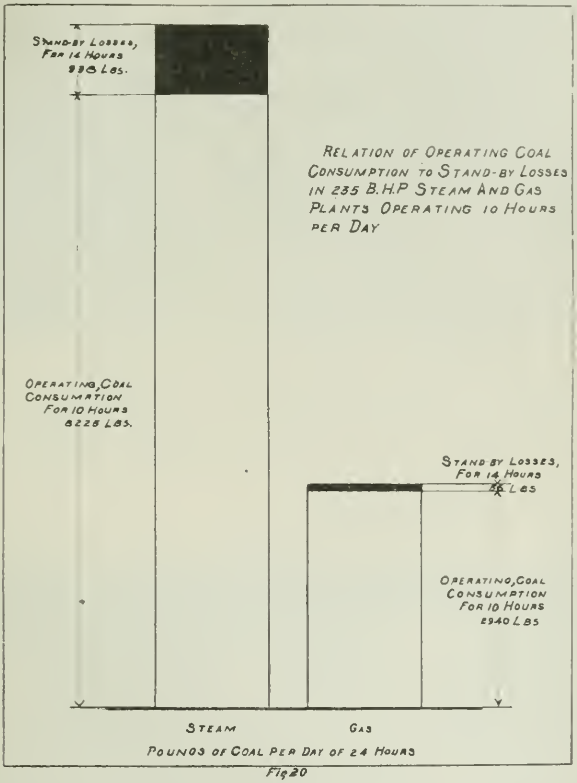


Fig 20

In considering the possible increases in efficiency of the boiler tests with a compound engine substituted for the simple engine used the fact should not be over-looked that a corresponding increase in the efficiency of the producer-gas tests may be brought about under corresponding favorable conditions.

Too much emphasis can not be given to the fact that all of the tests upon bituminous coals, lignites, and peats were made in a producer designed primarily for anthracite coal. It is in fact marvelous that any single plant can handle such a range of fuels. Not only is the producer passing through a transitional period, but the

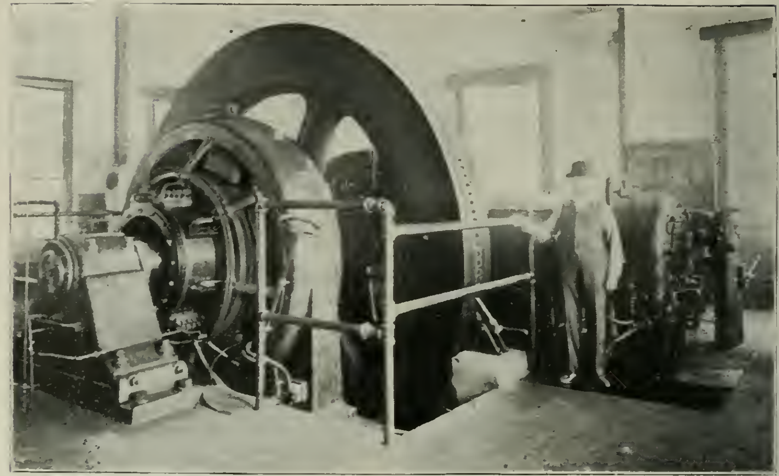


Fig. 21.
Horizontal Producer-Gas Engine Direct Connected to Electric Generator for Street Railway Service.

gas engine must still be regarded in the same light. In the larger sizes the vertical, single-acting engine is being replaced by the horizontal double-acting type. Other changes and improvements are constantly being made which tend to do for the efficiency of the gas engine what compounding and tripling the expansions have already done for the steam engine.

The engine used in the tests reported is, as already stated, of a type that is rapidly becoming obsolete for this size, viz., vertical, three-cylinder, single-acting.

A brief consideration of these points, will lead at once to the conclusion that the producer-gas plant and steam plant used in these tests compare very favorably, and that an increase in efficiency in the boiler tests that might result from using a compound engine can be off-set by the introduction of the more modern type of gas engine and a producer plant designed to handle the types of fuel used.

It should again be noted that many fuels are not fit for use under boilers. Many of these poor fuels have been used with the greatest ease in the gas producer thus opening the way for the utilization of many fuels that have heretofore been regarded as practically of no value. Several of the poorest grades of bituminous coals have shown remarkable efficiency in the gas producer, and the lignites and peat have also responded with great readiness to the demands of the gas-producer, thus opening the way to the introduction of cheap power into large districts that have thus far been commercially unimportant owing to the lack of industrial opportunities.

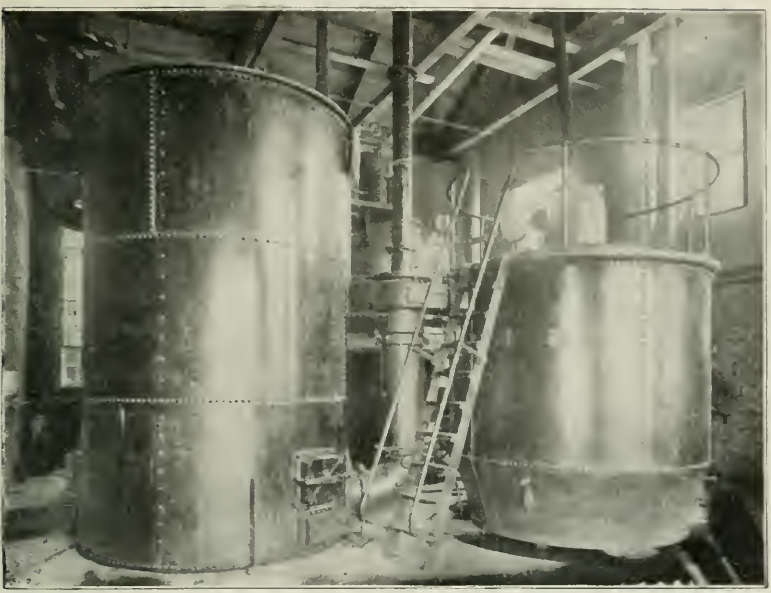


Fig. 22.
Westinghouse Pressure Gas Producer

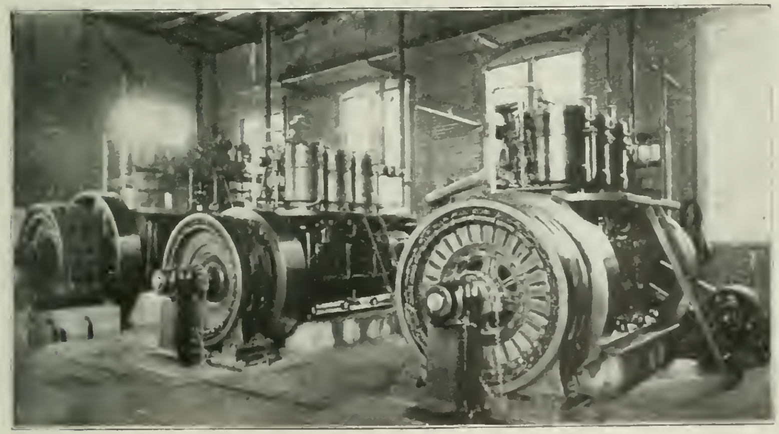


Fig. 23.
Installation for City Lighting

EFFICIENCIES.

It has not been the aim of the testing plant to determine the lowest possible amounts of coal that could produce a given power, or to determine the highest possible efficiency of the particular producer plant installed. The work of the plant was laid out by an act of Congress which restricted the work to the determination of the possibilities of utilizing the bituminous coals, lignites, and other fuels for the production of power. It is expected that many special investigations may be carried on in the future. In spite of the fact that no series or runs has been made on any one coal for determining the best possible results obtainable, it is nevertheless gratifying to report that official records have been made as low as 0.95 pounds of dry coal per hour burned in the producer per electrical horse-power developed at the switchboard; or 0.80 pounds of dry coal per hour burned in the producer per brake horse-power per hour, on the basis of an efficiency of 85 per cent. for generator and belt.

VIEWS OF THE MANUFACTURER.

In order to determine as closely as possible the exact status of the producer-gas business, an effort has been made to get at both the manufacturers' point of view and that of the owners and operators of existing plants.

With this in mind several manufacturers of gas producers were asked about a year ago:

"To what extent is the demand for gas engines and gas producers, and the interest in the same, growing?"

The replies were sufficiently significant to warrant their presentation at this time:

"We believe there is a waiting and almost unlimited demand for producer power plants, as soon as the manufacturers have something definite to offer and can guarantee quick installation and certain results."

"Would advise you that the demand for gas engines and gas producers is growing considerably. We have this month closed for an 8,000-horse-power gas producer plant, and have on our books negotiations pending for over 200,000 horse-power."

"The demand for gas engines and gas producers is at present apparently only limited by the output, we ourselves having orders way ahead, and all the business we can possibly fill. Were we to go out after business we would immediately swamp the factory. These plants are giving such excellent results in the field that they are bound to replace steam for almost all uses, and in consequence the field may be said to be almost unlimited."

"The demand for gas producers, and the interest manifested in the same, seems to be growing very rapidly, as indicated by the number of inquiries received at our office and by our agents in different parts of the country."

"According to inquiries which we are constantly receiving, we judge that the interest in the question of gas producers and gas engines is growing considerably, and all indications lead us to believe that the proposition of gas power plants will be a very important one in this country before long."

"We can only say that our correspondence indicates a continually growing demand for gas producers for power purposes, especially those adapted for running on soft coals."

"There has probably never been a mechanical production more widely or thoroughly advertised at such an early period in its history in this country as the suction producer gas power equipment. Much of this advertising has aroused curiosity among people, many of whom are not contemplating a purchase. On the other hand the fuel economy is so remarkable that manufacturers with a reputation for reliable goods, and with the fuel guarantees they offer, backed by unquestioned responsibility, are able to sell their product with very little effort."

"The gas producer business and the uses to which they have been applied have increased about 50 per cent. within the last ten years, and are still growing. We would imagine the next ten years would show a far greater improvement. We think producer gas is yet in its infancy as to various applications."

"The demand for gas engines and gas producers is growing in that field where the price of coal is highest, and for that reason any commercial tests in suitable gas producers, which will use the fuel of the district, will be of value."

"There is no doubt that the gas engine itself is now-a-days in such a state of perfection that its use is bound to become general for power production as soon as the possibility for using bituminous coal in gas producers to a large extent has been proven."

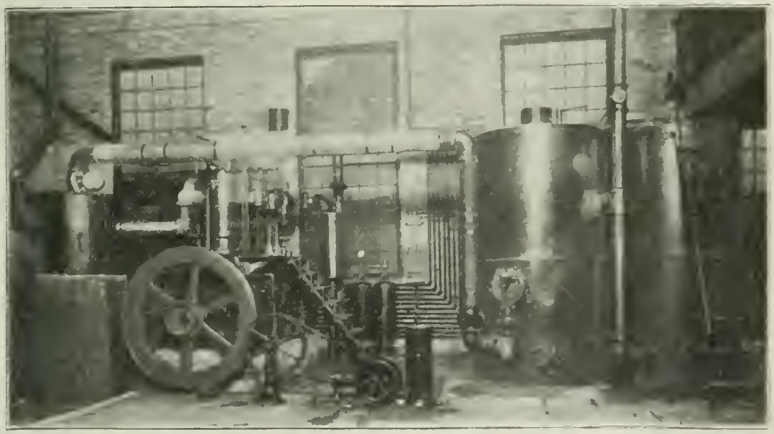


Fig. 24.

Suction Gas Producer Installation for Shop Drive, as Manufactured by the Smith Gas Power Company.

At the same time the manufacturers were asked:

"What are the serious difficulties in the way of more rapid development of gas producers and gas engines as a means of developing power?"

A summary of the replies would indicate the difficulties to be about as follows:

1. The fact that the gas engine is not yet as reliable as the steam engine.
2. The lack of engineers who know how to run producer gas power plants.
3. Incompetent salesmen—men not familiar with the details of the engines and producers they are handling.
4. Large number of unsuccessful and only partially successful installations made during the experimental period of this development.
5. Lack of proper design and construction of producer gas engines in the United States.
6. Lack of knowledge and confidence on the part of the public.
7. The fact that the heating of factory buildings must be provided for by a heating plant separate from the power plant
8. Lack of producer type which will gasify bituminous coal satisfactorily.
9. Inability to use cheap fuels in the suction gas producer.
10. Lack of complete knowledge as to how successfully the different fuels in the different localities of the country can be used in gas systems.
11. Large excess cost of gas engine—gas producer power plants over that of steam power plants.

THE SITUATION TODAY REGARDING THESE DIFFICULTIES.

It is certainly most hopeful when the manufacturers themselves are ready to acknowledge the difficulties outlined. This situation is in fact the most encouraging sign for the future development of producer-gas plants.

A year has elapsed since these communications were received. It is therefore well to examine the situation briefly but critically today, regarding the eleven difficulties listed above:

I. *The fact that the gas engine is not yet as reliable as the steam engine.*

There have been good grounds for the feeling that the gas engine was less reliable than the steam engine, but today many installations tend to change this impression.

Mr. Paul Winsor, Chief Engineer of Motive Power & Rolling Stock, Boston Elevated Railway Company, says, in an article on the producer-gas power plants installed by his company, "As a result of my experience with these plants, I am absolutely convinced of the economy and reliability of a gas engine power station."

In order to counteract any feeling of lack of confidence in the possibilities of continued operations of gas producers and gas engines, an endurance test was undertaken at the Testing Plant at

Saint Louis, which demonstrated beyond dispute the possibility of continuous operation of producer plants using bituminous coals for power purposes. The test in question began March 8, 1905, and continued until April 1, without interruption, twenty-four consecutive days.

This endurance test upon one coal was made possible through the kindness of Donk Brothers Coal and Coke Co. of St. Louis, who generously supplied the necessary 150 tons of coal. The coal was a lump coal from their mine No. 3, located near Troy, Illinois. The average of six analyses of this coal is as follows:

Proximate.

Moisture	14.68	per cent.
Volatile combustible	30.98	
Fixed Carbon	42.93	
Ash	11.41	
	100.00	per cent.
Sulphur	1.33	per cent.

With 12,343 British thermal units per lb. of dry coal.

During this entire test calorimetric determinations of the heat value of the gas were made every twenty minutes, and volumetric analyses were made every two hours. The average heat value of the gas for the entire run was 156.1 British thermal units per cubic foot, and the average composition of the gas was as follows:

Hydrogen disulphide (H_2S)	0.0	per cent.
Carbon dioxide (CO_2)	9.2	
Oxygen (O_2)	0.0	
Ethylene (C_2H_4)	0.4	
Carbon monoxide (CO)	20.9	
Hydrogen (H_2)	15.6	
Methane (CH_4)	1.9	
Nitrogen (N_2)	52.0	
	100.0	

During the progress of the test the usual observations were made at intervals of twenty minutes and careful notes kept of all incidents connected with the operation of the plant. Among the items of interest those relating to the tar extracted during the test are of special significance, as it has often been stated that no plant mechanically separating the tar could run more than five or six days without shutting down. The total tar extracted during this test amounted to 14,950 lbs., or about 143 lbs. of tar per ton of coal burned in the producer. By heating and stirring the tar, the water was extracted from this tar, and the figures given are for tar containing not over ten per cent. of water.

As the plant was laid out for general test purposes the passages through which the gas was obliged to pass were far more tortuous than would have been the case for the installation of a simple plant for power purposes. As a result, the gas in passing from the dust collector to the scrubber, instead of passing through a pipe about three feet in length, was forced to make three right angle turns and pass through a water seal valve, thus traversing a distance of about 20 feet. This construction, necessary only for testing purposes, was unfortunate, and owing to the deposit of tar in the water seal valve brought the test to a close after twenty-four days. With this unfortunate combination of piping removed, even more wonderful endurance records should be made than the surprising twenty-four-day test here recorded.

In order to remove the ashes which must be ground down at regular intervals it is usually considered necessary to shut down the entire plant. As such a shut-down would be fatal to an endurance test, a special method of removing the ashes had to be resorted to. The ashes were removed about once every forty-eight hours by simply reducing the pressure under which the producer was operated, and running the plant on the suction basis during the hour required for removing the ashes. The men worked with entire ease and comfort during this period.

During the entire twenty-four days the engine showed no signs of heating, clogging with tar, or other trouble. It ran steadily at all times and at the end of the test was found in perfect condition. The same set of igniters was used throughout the run and gave absolutely no difficulty. An inspection of the engine at the close of the test showed the cylinders, igniters, and all working parts. to be in such excellent condition that the engine was not even cleaned, or its mechanism in any way changed before beginning the next test. An inspection of the producer plant, at the close of the test, also showed everything about the plant to be in excellent condition, and the regular tests went on as usual after the close of the endurance run.

During this test an average of 225.5 brake horse-power was maintained. The coal consumed was 1.40 lbs. of dry coal per brake horse-power per hour. Especial attention is called to the fact that during this test, as well as during all other tests conducted at this plant, no attempt is made to remove the sulphur from the gas before it enters the engine. Considerable controversy has arisen in various parts of the country regarding the influence of sulphur upon the cylinders of a gas engine, leading in some cases to the introduction of this question into important lawsuits. The engine in use at the Testing Plant has received the full charge of sulphur contained in the gas, since the establishment of the plant, and shows absolutely no signs of injurious effects, although coals have been used running as high as 8.1 per cent. sulphur.

2. *The lack of engineers who know how to run producer gas power plants.*

It cannot be denied that many of the difficulties charged to producer gas power plants are due entirely to incompetent operators. Some plants have been temporarily put out of commission by the prejudices or lack of ability and training of operators or engineers in charge. In a few cases these failures are due to the impossibility of finding competent men to operate the plants, but in many cases it is undoubtedly due to a short-sighted policy on the part of the manufacturers, who are not willing to give the proper and necessary information about the design, construction, and operation of the plant in question. The possibility of *a sale* at the present time is apparently the only interest, and the future is allowed to take care of itself. My attention was directed to several such instances in visiting a number of installations a few months since.

3. *Incompetent salesmen—men not familiar with the details of the engines and producers they are handling.*

This condition of affairs has led to absurd guarantees and unfortunate installations, which have seriously interfered with further business in the same district.

One salesman, representing a house of national reputation, told me that their suction producer (at that time they had only one producer in existence, and that one was in their own factory) was guaranteed to operate perfectly on charcoal, anthracite coal, coke, bituminous coal, lignite, and peat. When I informed him that I was ready to buy out their whole producer business that day if his company would put that guarantee in writing, he became decidedly confused.

One agent "worked" an old gentleman in a small town by convincing him that a producer-gas plant was exactly adapted to the *intermittent* demands of a small gristmill. Today the mill may run two hours; tomorrow, seven; and then not again for two or three days. The salesman claimed that his producer plant would do everything exactly as desired, i. e., it was just the plant for *variable* demands.

As the old gentleman said, "He offered me a gold-brick and I bought it. There it stands."

The mill is now run by an electric motor supplied with current from the town lighting plant.

4. *Large numbers of unsuccessful and only partially successful installations made during the experimental period of this development.*

These are due in part to the willingness of small companies with little financial backing to allow the public to "be the dog" instead of thoroughly testing their plants before putting them out. The need of money, anxiety to get ahead of their competitors, lack of knowledge, incompetent designers, operators and salesmen, have combined in the past to produce an unfortunate situation, which, however, is rapidly clearing away.

5. *Lack of proper design and construction of producer-gas engines in the United States.*

This has undoubtedly been a serious difficulty. Many engines have failed utterly to meet the demands and have been withdrawn. Today the majority of manufacturers realize that a special engine must be designed for producer-gas work, and that an engine designed for city gas, or gasoline, and then "patched up" to work on producer gas is a sorry failure.

6. *Lack of knowledge and confidence on the part of the public.*

This lack has been largely due to the five difficulties already mentioned and will take care of itself as these are remedied.

7. *The fact that the heating of factory buildings must be provided for by a heating plant separate from the power plant.*

This may be a serious factor in some cases. Several companies claim to have this problem satisfactorily solved. It is by no means impossible of solution, and simple practical methods of utilizing the heat from the exhaust, or the producer-gas direct, will undoubtedly be brought forward in the near future.

8. *Lack of producer type which will gasify bituminous coal satisfactorily.*

There are today at least two types of producers which meet this demand reasonably well—the pressure and the down-draft plants. I am informed that there are in America at the present time producer-gas plants aggregating over 200,000 H. P. which operate on widely ranging qualities of fuel, from wood to the best grades of bituminous coal. The work accomplished by the United States Geological Survey Fuel Testing Plant certainly establishes beyond doubt the possibilities in this direction.

9. *Inability to use cheap fuels in the suction gas producer.*

This is a drawback to the proper development of the suction plant. Several companies claim to have solved this problem although official results are not yet available.

10. *Lack of complete knowledge as to how successfully the different fuels in the diwrent localities of the country can be used in gas systems.*

This has been the special investigation† of the United States Geological Survey Fuel Testing Plant for the past two and a half years.

11. *Large excess cost of producer-gas power plants over that of steam power plants.*

Although this undoubtedly has been true, the cost of gas plants is decreasing, and the statement above is at least open to discussion if not to contradiction in many cases.

Feeling that definite information relating to the cost of producer-gas installations is exceedingly difficult to find, an attempt has been made to secure the desired figures from all of the leading manufacturers in the United States. Although some have failed to respond, the results have been very gratifying and are presented in detail.

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† For detailed reports see Bulletins Nos. 261, and 290; Professional Paper No. 48 (3 volumes); and other reports on the subject published by the United States Geological Survey.

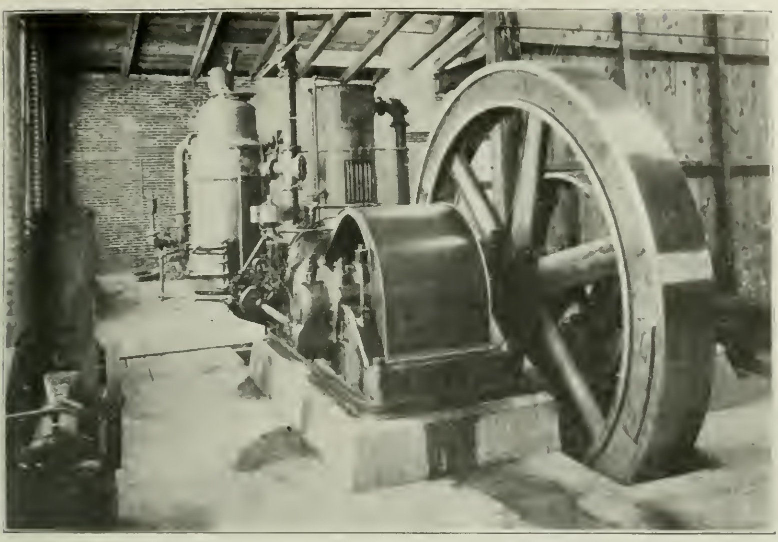

Fig. 25.

Suction Gas Producer Installation, as Manufactured by the Olds Gas Power Company.

Table III gives the cost of twenty-six down-draft, pressure, and suction plants of different sizes together with the cost of the gas engines; electric generators, auxiliary machinery, buildings, etc., being included wherever possible. The figures in each case are those supplied by the manufacturer.

Referring to the plant designated "K" it will be noted that the cost of this complete plant including electric machinery, buildings, etc., complete is $73 per horse power. I was informed that the corresponding figures for a competing steam plant amounted to $74 per horse power.

In table IV are presented the manufacturers' itemized estimates of the cost of operation, including fixed charges whenever possible, of several producer-gas installations. The plant designation used in this table corresponds to that of table III, i. e., the data in the two tables under the same designation letter, refer to the same installation.

An attempt was made to prepare a table of comparative costs of installation and of operating expenses for steam and for producer-gas installations. After considerable study of the situation it was decided that such a table would prove of little or no value as the relative cost of the installations may be made almost anything within a given range, to suit the individual fancy of the person making such comparisons—in favor of steam or gas as his inclination may dictate.

The conclusion arrived at is that the complete producer gas installation for the larger plants,—say from 4,000 or 5,000 horse power up—costs about the same as a first class steam plant of the same size. With the smaller installations the balance may be in favor of the steam plant. However, even if the steam plant cost 15 per cent less than the producer-gas plant it should not be forgotten that the increased efficiency in the operation of the latter will result in making up the difference in the first cost within a short time—probably about two years in the average plant. In case of plants of over 1,000 horse power, with coal at $2.75 or more per ton this difference in first cost is usually wiped out within the first year of operation.

In view of the difficulty involved in determining the exact basis of comparison of the costs of steam and producer-gas plants, I have decided to present the following very complete table given by Mr. Stott in his paper previously referred to, entitled, "Power Plant Economics."

"In this table," Mr. Scott says, "will be found a tabulation of the relative values of the various items necessary in the maintenance and operation of a power plant. The first column covers a plant with compound condensing reciprocating engines without superheat, and is derived from a year's record of actual costs of a large plant operating with a load factor of approximately 50 per cent; load factor in this case being defined as

$$\frac{\text{Actual Output}}{\text{Maximum hour's load x 24}}$$

The values in the other columns have in the main been estimated from the first column, but wherever possible actual data derived from various sources both domestic and foreign, have been used; but in all cases all values have been reduced so as to make them directly comparable with the first column, and with one another. The values in maintenance and operation of steam turbines are derived from actual costs."

Maintenance.	Reciprocating Engines	Steam Turbines	Reciprocating Engines and Stm.Turbines	Gas Engine Plant	Gas Engines and Stm.Turb's
1. Engine room mechanical	2.57	0.51	1.54	2.57	1.54
2. Boiler room or producer room	4.61	4.30	3.52	1.15	1.95
3. Coal and ash-handling apparatus	0.58	0.54	0.44	0.29	0.29
4. Electrical apparatus	1.12	1.12	1.12	1.12	1.12
Operation.					
5. Coal and ash-handling labor	2.26	2.11	1.74	1.13	1.13
6. Removal of ashes	1.06	0.94	0.80	0.53	0.53
7. Rock rental	0.74	0.74	0.74	0.74	0.74
8. Boiler-room labor	7.15	6.68	5.46	1.79	3.03
9. Boiler-room, oil, waste, etc.	0.17	0.17	0.17	0.17	0.17
10. Coal	61.30	57.30	46.87	26.31	25.77
11. Water	7.14	0.71	5.46	3.57	2.14
12. Engine room mechanical labor	6.71	1.35	4.03	6.71	4.03
13. Lubrication	1.77	0.35	1.01	1.77	1.06
14. Waste, etc.	0.30	0.30	0.30	0.30	0.30
15. Electrical labor	2.52	2.52	2.52	2.52	2.52
Relative cost of maintenance and operation	100.00	79.64	75.72	50.67	46.32
Relative investment in per cent.	100.00	82.50	77.00	100.00	91.20

Plant Designation
Manufacturers
Make
Type
Fuel Used
Horse Power
Weight, lbs.
Weight per Horse
Cost f.o.b. Factory.
Cost of Erecting.
Foundations, cu. ft.
Cost of Foundati
Buildings, cu. ft
Cost of Buildings,
Total Cost of Abov
Make
Type
Horse Power
Weight lbs.
Weight per Hor
Cost f.o.b. Facto
Cost of Erecting
Cost of Exhaust
Cost of Erecting
Cost of Starting
Cost of Erecting
Foundations, cu.
Cost of Foundatio
Buildings, cu. ft.
Cost of Buildings,
Total Cost of Abo
Kilowatts
Cost of Generato
Cost of Exciter,
Cost of Switchbo
Cost of Erecting
Horse Power of
Cost of Exciter E
Cost of Erecting
Total Cost of A
As Shown by Item
Gas Plant, Electric Foundations, Bui
Gas Producer Plan
Producer Plant Er
Producer Plant E
Engine f.o.b. Facto
Engine Erected Ex
Engine Erected In
Engine and Auxilia Foundations
Engine and Auxilia Foundations
Generator f.o.b. Fac
Generator and Aux
Buildings Erecte
Producer Plant and Exclusive of Fou
Producer Plant an Including Founda
Complete Plant E
Complete Plant E

Table III

COST OF PRODUCER-GAS INSTALLATIONS

GAS-PRODUCER PLANT.

1	Plant Designation	A or B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'
2	Manufacturers	Power and Mining Machinery Co.										Otto Gas Engine Works	*Minneapolis Steel and Mchy. Co	Otto Gas Engine Works	Smith Gas Power Co	Wile Power Gas Co.	Olds Gas Power Co.	Minneapolis Steel and Mchy Co.	Otto Gas Engine Works	*Minneapolis Steel and Mchy Co.		Olds Gas Power Co.	R.D. Wood and Co.			R.D. Wood and Co.	
3	Make	Loomis-Pettibone.										Otto	M.S. and M.Co.	Otto	S.G.P.Co.	Wile	Pintsch		Otto								
4	Type	Down Draft.							5-10×16 Generators		8-11×10 Gas Generators	Suction	Suction	Suction	Suction	C - Suction Pressure	Suction	Suction	Suction	Suction	Suction	Suction	Suction			Pressure 2 Units	
5	Fuel Used	Bitumenous Coal.										Anthr.	Anthr.	Anthr.	Anthr.	Anth. and Indiana Bit.	Anthr.	Anthr.	Anthr.	Anthr.	Anthr.	Anthr.	Anthr.			Anth. Bit. and Lig.	
6	Horse Power	250	300	1000	2000	2000 Max 2,500	4,000 Max 5,000	4,500	4,500	4,500	3,500	20	25	60	60	125	75		110	110	160	200	300			500	
7	Weight, lbs.	174,600		159,000	650,400						1,000,000		8,000			38,000		9500		12,000	14,000		58,000			140,000	
8	Weight per Horse Power, lbs	700		159	325								145			302				109	87.5		193			280	
9	Cost f.o.b. Factory, $	8090		10,304	33,060						64,000		1030	1360	1100	2800		1200	1650	1900	5300	2500	4300			9500	
10	Cost of Erecting $	1350		5,100	3,700										130	160							960			3500	
11	Foundations, cu. ft.	750			2,140										30	60		200			400					375	
12	Cost of Foundations, $	185			25¢ cu.ft. = 535																		75			244	
13	Buildings, cu. ft.				57,700																		16,000				
14	Cost of Buildings, $				10¢ cu.ft. = 5,770																		1,600			3800	
15	Total Cost of Above Items, $	9629		21,404	33,089							925	1050	1360	1260	2960		1200	1650	1900	3,300		6.875			17,044	

*Prices given are subject to change with variation in cost of material

GAS-ENGINE.

	Plant Designation	A or B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'
16	Make	Snow		Snow	Snow						Snow	Otto					Olds										
17	Type		2-22 H.P.	Twin Tandem Double Acting 4 cyl 19×30 500 H.P.	Twin Tandem Double Acting	3 - Twin Tandem Double Acting 1400 H.P. each	3-Twin Tandem Double Acting 1800 H.P.	3-1300 K.W. Direct Conn	3-1600 H.P.	4-Twin Tandem Double Acting 1000 H.P.	3-1100 H.P. 33×48 Single Tandem		Single		Two-cyl. Vertical	Twin Single Acting Riverside	Horizontal Single Acty. (New Type) 16¼-20	Single		Twin	Twin			Single Acting	Double Acting		Single Acting
18	Horse Power	250	440	1000	2000	2000	5400	4800	4800	4000	5500	20	55	60	60	73		80	110	110	160			400	400		600
19	Weight, lbs	43800		154000	850,900						2,625,000		21,000			28,000		32,000		e 20,000	52,000			85,000			110,600
20	Weight per Horse Power, lbs	175		154	425								300			372		400		182	325			212			184
21	Cost f.o.b. Factory $	6250		33,000	64,000						205,000	1,100	2,200	2,750	2600	2,950		3,300	4,750	3,800	5,200			12,800	12,000		17,480
22	Cost of Erecting Engine $	130		300	600											125											
23	Cost of Exhaust and Air Piping, $	100			330							55	200	150	30	110		170	200	e 600	350						
24	Cost of Erecting item 23. $	20			30											20											
25	Cost of Starting Device, Tank and Compressor, $	310		730	300						Starting Device and Incidentals 3000				150	550		220		360	400						
26	Cost of Erecting Item 25. $				23											25											
27	Foundations cu. ft.	2160			5400										330	375		1400			2,000						
28	Cost of Foundations, $	27¢ = ft = 580			26¢ cu.ft. = 1400							30		150					225								
29	Buildings, cu. ft.				30,000																						
30	Cost of Buildings, $				30¢ cu.ft. = 9,000																						
31	Total Cost of Above Items, $	7370		34,050	76,125							1,205	2,400	3,050	2,800	3,760		3600	3175	4960	6250						

e Special exhaust pipe used

ELECTRIC GENERATOR.

	Plant Designation	A or B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'
32	Kilowatts	130		400	1500						3-800-4000					50 ?		55		75	120						
33	Cost of Generator, $	2000		14,200	14000						44,000					525 ?											
34	Cost of Exciter, $	150			757						Switchboard Instruments and Connections 16,000																
35	Cost of Switchboard, $	250			300											125 ?											
36	Cost of Erecting Items 33, 34, and 35, $				300											100 ?											
37	Horse Power of Exciter Engine	10			30																						
38	Cost of Exciter Engine f.o.b. Factory, $	260			2,430																						
39	Cost of Erecting Exciter Engine, $	30			60																						
40	Total Cost of Above Items, $	2690			10 247											750											

TOTAL COST OF COMPLETE PLANT ERECTED. $

	Plant Designation	A or B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'
41	As Shown by Items Given Above	a 23180		69654	127,461							2,170	3,450			7,480		f 4865			g 3750		6875				
42	Gas Plant, Electrical Machinery, Pipings Foundations, Buildings, Etc.		35,000			212,817	310,000	380,000	345,600	275,000	385,000																

a Includes $3500 for bldgs

f Includes $75 for circulating pumps

g Includes $200 for circulating pumps

COST PER H.P. $

	Plant Designation	A or B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A'
43	Gas Producer Plant f.o.b. Factory	32.5		18.5	16.5						12.0	46.5		22.6	18.5	22.3			15.0			12.4	14.5			19.0	
44	Producer Plant Erected Exclusive of Foundations	36.0		21.5	13.5								19.0		21.0	25.5				17.4	20.8		17.3			26.0	
45	Producer Plant Erected Including Foundations	38.5			13.5																		17.6			28.0	
46	Engine f.o.b. Factory	25.0		33.0	32.0						37.5	35.0		46.5	43.5	39.6			45.0		34.5			32.0	30.0		29.0
47	Engine Erected Exclusive of Foundations	25.5		33.5	32.5								43.5			41.0		41.5		42.0							
48	Engine Erected Including Foundations	20.0			33.0																						
49	Engine and Auxiliaries Erected Exclusive of Foundations	27.0		34.0	33.0											50.5		46.0		49.0							
50	Engine and Auxiliaries Erected Including Foundations	29.5			33.5																						
51	Generator f.o.b. Factory	10.0		26.5	7.0						8.0					8.0											
52	Generator and Auxiliaries Erected				9.0											11.0											
53	Buildings Erected	14.0			7.5																		5.6			7.6	
54	Producer Plant and Complete Engine Erected Exclusive of Foundations	65.0		55.5	46.0						65.5	109	62.5	69.5		b 90	86.6	e 62.0	60.4	62.5							
55	Producer Plant and Complete Engine Erected Including Foundations	68.0			47.5							109.5		74.5					64.0								
56	Complete Plant Erected Exclusive of Buildings	73.0		69.5	56.5											100.0											
57	Complete Plant Erected Including Building	93.0	b 79.5		63.5	b 76.0	c 77.3	b 75.5	b 72.0	69.0	d 70.0																

b Based on engine H.P.

c Based on 4000 H.P.

d Total freight $15000 Cost of plant erected, ready to run, including freight, $73. per H.P.

Table IV

— ESTIMATED OPERATING COSTS OF PRODU

1	Plant designation.	A	B	C	D	E
2	Type of gas plant and horsepower of producer.	Down-draft 1 unit - 250 H.P.	Down-draft 1 unit - 250 H.P	Down-draft 1 unit - 500 H.P	Down-draft 1 unit - 1000 H.P.	Down-draft 1 unit - 2000 H.P
3	Type of engine and horsepower	Twin tandem, double-acting. 1 - 250 H.P	Twin tandem, double-acting 1 - 250 H.P.	2 - 220 H.P. gas engines.	2 Twin tandem. 18x30 double-acting 2 - 500 H.P	Twin tandem, double-acting 1 - 2000 H.P.
4	Service	60 hours weekly	6 Mo. 123 hours weekly 6 Mo. 154.5 " "	144 hours weekly.	60 hours weekly.	158 hours weekly.
5	Load factor	75% = 188 H.P.	(a) Day load 75% = 188 H.P. (b) Night " 50% = 125 H.P.	(a) Day 75% = 330 H.P (b) Night 33⅓% = 147 H.P.	90% = 900 H.P	(a) Day 75% = 1500 H.P (b) Night 50% = 1000 H.
6	Guarantees. Engine - B.T.U. per B.H.P hour. Producer - Efficiency.	Engine. Producer. 12000 B.T.U 80% with 13500 B.T.U. coal	Engine. Producer on (a) 12000 80% on (b) 13500 65% with 13500 B.T.U. coal	Engine. Producer on (a) 11000 84% on (b) 12000 80% with 13500 B.T.U. coal.	Engine Producer 12000 80% with 13500 B.T.U. coal.	Engine Produce on (a) 10,500 83% on (b) 11500 75% with 13500 B.T.U. coal
7	No. operating days considered in estimate	365	365	365	365	365
8	Tons of coal and price.	10 hrs for 313 days = 171.8 tons. at $2.75	on (a) 125 hr. x 313 d. = 168 ton. on (b) {9 " x 182 " / 13.5 " x 183 "} = 354 " Total 522 ton at $2.75	on (a) 10 hr. x 313 d. = 450 ton on (b) 14 " x 313 d = 320 " Total - 770 ton at $2.75	10 hrs. x 313 days = 1397.3 ton at $2.75	on (a) 10 hr. x 313 d. = 1965 to on (b) 14 " x 365 d. = 2595 " Total - 4560 ton at $2.75
9	Gals of oil and price.	2 gals per day x 313 x 30¢	8 gals. daily x 313 at 30¢ 1.5 " Sunday x 52 " "	2 gals daily x 313 at 30¢	6 gals daily x 313 at 30¢	20 gals. daily x 365 at 3
10	Lbs waste and price	1500 lbs at 7¢ per lb.	2000 lbs. at 7¢	4 Bales = 2000 lbs at 7¢	2000 lbs. at 7¢	10 Bales = 5000 lbs at 7
11	Engine room labor and wages	1 engineer at $17. weekly	2 engineers at $17. weekly	2 engineers at $17 weekly	1 engineer at $17. weekly 1 helper " $15. "	2 engineers at $3. per da 2 oilers " $1.50 " "
12	Gas-house labor and wages.	1 gas operator at $15. weekly	2 gas operators at $15. per week.	2 gas operators at $15. weekly.	1 gas operator $15. weekly.	2 gas operators at $2.2 2 helpers " $1.50
13	Extra cleaning	$4.50 weekly	$4.50 weekly	$4.50 weekly	$4.50 weekly	$6.00 weekly
14	Total gals of water	Engines 940 gals. per hr. Produder 564 " " " Total = 4,394,520 gal. at 2¢ M.	Engine {Day 940 gals. per hr / Night 625 " " "} Producer {Day 564 gals per hr. / Night 375 " " "} Total = 5,510,000 gal at 2¢ M	Engines {Day 1650 gals. per hr. / Night 1000 " " "} Producers {Day 825 " " " / Night 450 " " "} Total = 14,100,000 gal. at 2¢ M.	Engine 4500 gals. per hr. Producer 2700 " " " Total = 22,536,000 gals at 2¢ M	Engines {Day 7500 gal per hr / Night 5000 " " "} Producer {Day 4500 " " " / Night 3000 " " "} Total = 29,415,000 gal. at 2¢ M
15	Total cost of coal (item 8)	$473.00	$ 1445.00	$ 2118.00	$4243.00	$ 12540.00
16	" " " oil (" 9)	188.00	305.00	188.00	564.00	2190.00
17	" " " waste (" 10)	70.00	140.00	140.00	140.00	350.00
18	" " " engine room labor (item 11)	884.00	1768.00	1768.00	1404.00	3285.00
19	" " " gas-house " (" 12)	780.00	1560.00	1560.00	780.00	2738.00
20	" " " extra cleaning (" 13)	234.00	234.00	234.00	234.00	312.00
21	" " " water (" 14)	98.00	110.00	282.00	450.00	1569.00
22	Operating expenses only.	$2727.00	$ 5562.00	$ 6290.00	$ 7815.00	$22984.00
23	Interest on investment	5% on $23200 = 1160.00	5% on 23200 = 1160.00	5% on 35000 = 1750.00	5% on 70,000 = 3500.00	5% on 127,500 = 6375.0
24	Depreciation on gas plant, bldgs. and foundations	5% on 13800 = 690.00	5% on 13800 = 690.00	5% on 11,700 = 585.00	5% on 22500 = 1125.00	5% on 43,500 = 2175.0
25	" " gas engines, electrical machy. etc.	6% on 9400 = 564.00	6% on 9400 = 564.00	6% on 23,300 = 1398.00	6% on 47500 = 2850.00	6% on 84,000 = 5040.0
26	Insurance, repairs, taxes etc	5% = 1160.00	5% on 23200 = 1160.00	5% on 35000 = 1750.00	5% on 70000 = 3500.00	5% on 127,500 = 6375.0
27	Total operating cost and fixed charges	$6301.00	$ 9136.00	$11773.00	$18790.00	$42929.0
28	Total K.W. hrs.	352125	650262	1142450		7,353,750
29	Cost per K.W. hrs	1.7¢	1.4¢	1.3¢	0.7¢	0.58¢

Table IV

G COSTS OF PRODUCER—GAS PLANTS —

D	E	F	G	H	I	J	K
-draft it - 1000 H.P	Down-draft 1 unit - 2000 H.P	Down-draft 2000 H.P Max. 2500 H.P.	Down-draft 4000 H.P Max. 5000 H.P	Down-draft 4500 H.P.	Down-draft. 3-10x16 Gen. - 4500 H.P	Down-draft 4500 H.P.	Down-draft. 3-11x18 Gen -5500 H.P.
vin tandem. o double-acting 500 H.P	Twin tandem, double-acting 1 - 2000 H.P.	2 Twin tandem, double-acting.	3 Twin tandem. double-acting.	3 Direct connected 3 - 1200 K.W.	3-1600 H.P. gas - engines.	4 Twin tandem. double-acting 4 - 1000 H.P.	5 - 33x48 Single tandem Snow engines 5 - 1100 H.P.
ours weekly.	158 hours weekly.			Lighting 4000 hours yearly.	4000 hours yearly.	Winter 161 hrs a wk. Summer 158 " " "	Continuous
% = 900 H.P	(a) Day 75% = 1500 H.P. (b) Night 50% = 1000 H.P	50% = 1400 H.P	50% = 2700 H.P	Approx. 2240 K.W	80% = 2760 K.W.	Winter (a) 75% = 9 hrs (b) 66% = 7 " (c) 100% = 8 " Summer 75% = 15 h. 100% = 2 " 66% = 7 "	80% of 3200 K.W. = 2560 K.W.
ine Producer o 80% 13500 B.T.U. coal.	Engine Producer on (a) 10,500 83% on (b) 11500 75% with 13500 B.T.U. coal.	Engine Producer 13600 80% with 13500 B.T.U. coal	Engine Producer 13600 80% with 13500 B.T.U. coal			Engine Producer on (a) 11400 80% " (b) 13000 80% " (c) 10500 83% with 13500 B.T.U. coal.	
365	365	365	365	365	365	365	365
s. x 313 days = 1397.3 at $2.75	on (a) 10 hr. x 313 d. = 1965 ton on (b) 14 " x 365 d. = 2595 " Total-4560 ton at $2.75	20 hr. x 365 d. = 5750 ton at $2.75.	20 hr. x 365 d. = 11081 ton at $2.75.	2 lbs. per K.W. hr 2 x 4000 hr x 2240 K.W. = 8000 ton at $2.75	1.75 lbs. per K.W. hr. 1.75 x 4000 hr x 2760 K.W. = 8611 ton at $2.75	Winter 3208 ton. Summer 4974 " Total-8182 ton at $2.75	1.80 lbs. per K.W. hr. 50 ton per day x 365 = 18250 ton at $2.50
s daily x 313 at 30¢	20 gals. daily x 365 at 30¢	20 gals. daily x 365 at 30¢	40 gals. daily x 365 at 30¢	10 gals. daily x 365 at 30¢	20 gals. daily x 365 at 30¢	30 gals daily x 365 at 30¢	20 gals. daily x 365 at 30¢
o lbs. at 7¢	10 Bales = 5000 lbs at 7¢	12 Bales = 6000 lbs at 7¢	24 Bales = 12000 lbs. at 7¢	10 Bales = 5000 lbs. at 7¢	10 Bales = 5000 lbs at 7¢	15 Bales = 7500 lbs. at 7¢	10 Bales = 5000 lbs. at 7¢
ineer at $17. weekly per " $15. "	2 engineers at $3. per day 2 oilers " $1.50 " "	2 engineers at $3 per day 2 oilers " $1.50 " "	2 engineers at $3. per day 2 helpers " $1.50 " "	2 engineers $100 monthly 2 oilers $60. "	2 engineers $80. monthly 2 oilers $45. "	2 engineers at $3. daily 2 oilers " $1.50 "	1 ch. eng. at $100 monthly 3 Asst. " " $17. weekly 3 oilers " $12. "
operator $15. weekly	2 gas operators at $2.25 2 helpers " $1.50	2 gas operators at $2.25 2 helpers " $1.50	2 gas operators at $2.25 2 helpers " $1.50	2 gas operators at $80 2 helpers " $50	2 gas operators at $60 2 helpers " $45.	2 gas operators at $2.25 2 helpers " $1.50	2 gas operators at $60 4 helpers " $45
o weekly	$6.00 Weekly			$312.00 yearly		$6.00 Weekly	
ne 4500 gals. per hr. lucer 2700 " " " l = 22,536,000 gals at 2¢ M.	Engines {Day 7500 gal. per hr. {Night 5000 " " " Producer {Day 4500 " " " {Night 3000 " " " Total = 29,415,000 gal. at 2¢ M.	Engines 8400 gals. per hr. Producer 4200 " " " Total = 100,000,000 gal. at 2¢ M.	Engines 16800 gals. per hr Gas house 8400 " " " Total = 183,960,000 gal at 2¢ M	Engine and producers 7.5 gals. per B.H.P. hrs Total = 115,200,000 gal. at 2¢ M	Engine and producer 7.5 gal. per B.H.P. hr. Total = 115,200,000 gal at 2¢ M	Eng {Winter = 41,650,000 gals. {Summer = 52,619,000 " Prod. yearly = 56,561,000 gals. Total = 150,830,000 gal. at 2¢ M	Engines and producer 7.5 gals. per B.H.P. hr. Total = 231,264,000 gal. at 2¢ M
43.00	$ 12540.00	$ 15812.50	$ 30473.00	$ 22000.00	$ 23680.00	$ 22500.00	$ 45625.00
64.00	2190.00	2190.00	4380.00	1095.00	1095.00	3285.00	2190.00
40.00	350.00	420.00	840.00	350.00	350.00	525.00	350.00
4.00	3285.00	3285.00	3285.00	3840.00	3000.00	3285.00	5684.00
80.00	2788.00	2737.50	2738.00	3120.00	2520.00	2738.00	2520.00
34.00	312.00			312.00		312.00	
50.00	1569.00	2000.00	3680.00	2304.00	2304.00	3016.00	4625.00
$ 7815.00	$ 22984.00	$ 26,445.00	$ 45396.00	$ 33021.00	$ 32949.00	$ 35661.00	$ 60994.00
n 70,000 = 3500.00	5% on 127,500 = 6375.00	5% on 212,817 = 10,641.00	5% = 15500.00	4% on 380,000 = 15200.00	5% 345600 = 17280.00	5% on 275,000 = 13750.00	5% on 400,000 = 20000.00
on 22500 = 1125.00	5% on 43,500 = 2175.00	5% on 57,017 = 2,851.00	5% = 3815.00	5% = 5500.00	5% = 5520.00	5% = 13750.00	6800.00
on 47500 = 2850.00	6% on 84,000 = 5040.00	6% on 155,800 = 9348.00	6% = 14022.00	6% = 16200.00	6% = 14112.00		6% = 15840.00
on 70000 = 3500.00	5% on 127,500 = 6375.00	5% on 212,817 = 10,641.00	5% = 15500.00	7600.00	2% = 6912.00	5% = 13750.00	2% on 400,000 = 8000.00
$ 18790.00	$ 42929.00	$ 59,926.00	$ 93542.00	$ 77521.00	$ 76773.00	$ 76911.00	$ 111634.00
	7,353,750	7,300,000	14,600,000	8,960,000	11,040,000	13,897,290	2,245,600
0.7¢	0.58¢	0.822¢	0.64¢	0.86¢	0.68¢	0.5¢	0.49¢

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[illegible]

Table IV

—ESTIMATED OPERATING COSTS OF PRODUCER—GAS PLANTS—

1	Plant designation	L	N	O	R	S	U	W	Z
2	Type of gas plant and horsepower of producer	Suction 1 unit = 20 H.P.	Suction 1 unit = 60 H.P	Suction 1 unit = 60 H.P.	Suction	Suction 1 unit = 110 H.P	Suction 1 unit = 160 H.P	Suction 1 unit = 300 H.P	Pressure 2 units - total 500 HP
3	Type of engine and horsepower	1-20 B.H.P	1-60 B.H.P	2 cylinder vertical 1-60 H.P.	Single engine 1-80 H.P	1-110 B.H.P	Twin engine 1-160 H.P.		
4	Service			144 hrs. weekly	98 hrs. weekly in Winter		55 hrs. weekly	120 hrs. weekly.	144 hrs weekly.
5	Load factor			(a) Day 55% = 33 H.P (b) Night 63% = 37.5 H.P	(a) night = 50%		(a) day = 89%	(a) day 100% (b) night 50%	(a) day 100% (b) night 75%
6	Guarantees Engine - B T U per B H P hour			Engine Producer 75% L.F - 11,000. 80% 50% L.F. - 13000. 75% 12500 B.T.U. coal.	on (a) 1.2 lbs. coal per B.H.P. hr 13500 B.T.U. coal		on (a) 0.9 lb coal per B.H.P hr 13500 B.T.U. coal	Engine Producer on (a) 11,000 80% on (b) 14000 75% 12500 B.T.U. coal	Engine Producer on (a) 11,000 80% on (b) 12,000 78% 12,000 B.T.U coal.
7	No of operating days considered in estimate	1 year = 3000 hrs	1 year = 3000 hrs	26 days		1 year = 3000 hrs		6 days and 5 nights	6 days
8	Tons of coal and price	1.5 lbs per B H.P hr at $4.25 per 2240 lbs.	1.5 lbs. per B H.P hr at $4.25 per 2240 lbs	10.4 Tons at $4.90 per ton		1.25 lbs. per B.H P hr at $4.25 per 2240 lbs.		26 tons at $3.00 per ton	Day-575 lbs. per hr Night-480 " " " Total- 76 ton at $2.50
9	Gals. of oil and price								
10	Lbs waste and price								
11	Engine room labor and wages	3 hrs per day at 15¢	4 hrs. per day at 15¢	3 hrs. per day at 20¢		4 hrs. per day at 20¢			
12	Gas-house labor and wages							1 gas maker at $2. per d. 1 ashman 1/4 day " $1.60 " "	2 gas makers @ $2 per d 1 helper " $1.60 " "
13	Extra cleaning								
14	Total gals of water							Producer-day-450 gal per hr Night-225 gal per hr Total, 40500 gals at 6¢ M	Prod.-Day-750 gal per hr Night-562 " " " Total-188,928 gal. at 6¢ M
15	Total cost of coal (item 8)	$171.00	$512.00			$783.00		$78.00	$190.00
16	" " " oil (" 9.)	90.00	216.00			330.00			
17	" " " waste (" 10.)								
18	" " " engine room labor (item 11)	135.00	180.00			240.00			
19	" " " gas-house " (" 12.)							24 40	33.60
20	" " " extra cleaning (" 13)								
21	" " " water (" 14.)							2.43	11.34
22	Operating expenses only	$396.00	$908.00			$1353.00		$104.83	$234 94
23	Interest on investment	326.00	669.00			1035.00		(1 yr = 300 days) 15.12	(1 yr = 300 days) 32.16
24	Depreciation on gas plant, bldgs, and foundations								
25	" " gas engines, electrical machy etc.								
26	Insurance, repairs, taxes, etc								22 08
27	Total operating cost and fixed charges	$722.00	$1577.00			$2388.00		$119.95	$289.18
28	Total K W hrs								
29	Cost per B H P hr (cents)	Coal $3.25 per ton = 1.14 " $4.25 " " = 1.20 " $5.00 " long " = 1.25	Coal $3.25 per ton = 0.81 " $4.25 " " = 0.88 " $5.00 " long " = 0.93			Coal $3.25 per ton = 0.67 " $4.25 " " = 0.72 " $5.00 " long " = 0.77			

Plant No	Type of Prod Plant and HP		No. and	ed for
1	*S	25	1	
2	S	25	1	surfacers, roughers etc.
3	S	30	1	
4	S	30	1	y.
5	S	35	1	ting cafès etc
6	S.	50	1	and carpenter shop
7	S.	50	1	
8	S	50	2-	wn.
9	S	60	1	100 light dynamo.
10	S	60	1	
11	S	60	1	achines.
12	S	70	1	to reservoir.
13	S	75	1	g. polishing etc.
14	S	75	1	
15	S	80	1	
16	S	90	1	lighting.
17	S	100	1	inting-presses.
18	S	100	2-50	for machine-shop drive.
19	S	125	1	
20	S	125	1	r machinery.
21	S	150		efore shipping.
22	S.	150	2-a	g purposes
23	S		1	
24	S	200	2-	es.
25	S.	200	1	
26	°p.	250	3-0 2-1 1	ent lights.
27	p	250	1	wer in scouring
28	p.	250	1	for general
29	p	400	8-a 1 2-9 3- 1 1	Pintschgas compressor.
0	p	1750	3	y service.
1	dd		3-	ses
2	dd	1000	4 as 3 1	vice about works.
3	dd	1500	2-61	service.
4	dd	4000	5-16	

*S= suction. °p= p

Table V

DATA FROM PERSONAL VISITS TO PRODUCER GAS PLANTS.

Plant No	Type of Prod Plant & HP	No of Engines and HP	Load Carried	Hours per Day.	No of Men required Each Shift	Fuel used and Cost per Ton.	Fuel per B.H.P. hour Lbs	Power used for
1	[a]S 25	1 25		Variable		Penn anthracite $4 35		Grist mill machinery
2	S 25	1 27	Variable - claim over 30 HP as max.	9-12	1	do		Air compressors, stone-surfacers, roughers etc
3	S. 30	1 30	28 HP.	10	5 hrs time of one man	do 6.00	1.1	Machine shops.
4	S 30	1 27	From ⅔ to full.	10	Part time of one	do. 3.20		Brick-making machinery.
5	S 35	1 35	1 - 24 K.W.	24	1	do 6 74		Ice making plant, lighting cafès etc
6	S. 50	1 30	30 H.P	10	1½ to 2 hrs time of one	do. 3 - 3.50	1.25	Electric lights - Forge and carpenter shop machinery.
7	S. 50	1 50	Ave 40 - often 50	10	2 hrs time of one	do. 4 00		Planing mill machinery.
8	S 50	2 - 25 each	50 HP at times	8-12		do —		Pumping water for town
9	S 60	1		10	1.	Charcoal 13.00	1 0	Shoe-shop machry - 100 light dynamo.
10	S 60	1 25	20 H.P.	10	2 hrs time of 1 at $2 per d.	Anthr. (Lackawanna No 1 pea) 4 75		Shop machinery.
11	S 60	1 50	30 HP.	10	Part time of 2	Penn. anthracite 4.50	1.50 for 20 H.P. load. 1.25 " 30 " " 1.00 " 50 " "	Lights - 225 sewing-machines.
12	S 70	1 65	About 20 HP	Var. up to 22	1	Anthracite		Pumping water from well to reservoir.
13	S 75	1 75						Machinery for Grinding, polishing etc.
14	S 75	1 60		20	Part time of 1.	Penn. anthracite		Shops
15	S 80	1 70			1 Operator - 1 helper.	Anthracite.		Electric Lighting.
16	S 90	1 80				Penn. anthracite		Municipal pumping and lighting.
17	S 100	1 55		24	1.	do.		Electric lights and printing-presses.
18	S 100	2 - 50 each				do. 4.50 to 5.75		Auxiliary to steam plant for machine-shop drive.
19	S 125	1 75	Claim 90 HP	22.5	1	do 5.50	Less than 1	Shops.
20	S 125	1 125		11		do.		Operating grain elevator machinery.
21	S 150		Variable	Variable		do.		Testing gas engines before shipping.
22	S. 150	2 - a 85 b 40	70 H.P	11		do.	18 with stand-by losses	General manufacturing purposes.
23	S	1 150				Anthracite		
24	S 200	2 - 100 each		11		Penn anthacite	1.	General m'f'g purposes.
25	S. 200	1 100			Part time of 1 at $1 75 per d.	do. 4.10		do.
26	[b]p. 250	3 - as follows 2 - 125 each 1 165	20-90 K.W.	24	2.	Anthr. in Producer 4.50 Bituminous in auxiliary boiler. 4.50	1 - 1.4	Street and incandescent lights.
27	p 250	1 89		10	Part time of 1 under supervision	Penn. anthracite		Electric light and power in scouring and dyeing plant.
28	p. 250	1 250	225 H.P.	11	1 for producer - 1 for both gas and steam-engines.	Bituminous (Big Muddy Ill.)		Generating electricity for general purposes.
29	p. 400	8 - as follows 1 85 2 - 90 each 3 - 45 each 1 19 1 38	45 HP. Full load ? ? ?	21 13 18 6 14 - 20	1 in producer room 1 in engine room. 1 for outside engines.	Penn anthracite 1 30 Runs from 1 25 to 1.50.	1.33	Incandescent lights Arc lights 2 air-compressors - 1 Pintsch gas compressor. Ash conveyor. Coal conveyor.
30	p 1750	3				Penn. anthracite		General street railway service.
31	[c]dd	3 - 235 each	260 K.W. ave.	24		Bitum. run-of-mine 2.30	1.4	General m'f'g purposes
32	dd 1000	4 as follows 3 125 1 165				do. —		Lights - general service about works.
33	dd 1500	2 - 610 each		16	1 for prod. 2 for engines.	Bitum. (Poçahontas)	1.1	General street railway service.
34	dd 4000	5 - 160 each	Full and over.	14		Bituminous.		Shops. etc.

[a]S = suction. [b]p = pressure. [c]dd. = down-draft.

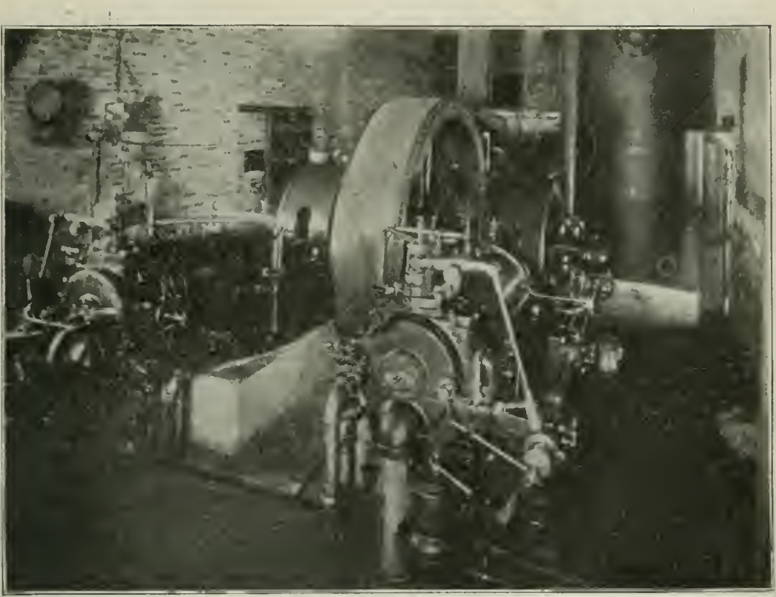


Fig. 26.
Suction Gas Producer Installation, as Manufactured by the Minneapolis Steel & Machinery Company.

VIEWS OF OWNERS AND OPERATORS OF PRODUCER GAS PLANTS.

There are today probably twenty companies in the United States manufacturing gas producers for power purposes. At least twelve of these are fully established on a commercial basis and are in position to give proper guarantee when installing plants.

About one hundred and fifty gas producer power plants ranging in size from 20 to 6,000 horse power are now in operation in the United States. One company alone reports twenty odd installations averaging over 2,000 H. P. each, and nearly as many more, averaging about the same size, contracted for or now being erected.

The number of installations and the persistent development has already led the National Board of Fire Underwriters to issue special rules and requirements for the "Construction, Installation and Use of Coal Gas Producer (Pressure and Suction Systems)."

Of the total number of installations in the United States it is interesting to note that about two-thirds are suction plants which operate on anthracite coal, charcoal being used in a few cases. Bituminous coal is used in approximately one-third of the installations, but this one-third of the number of plants probably covers in the neighborhood of 65 per cent to 75 per cent of the aggregate horse power rating.

During the past summer it was my privilege to visit several of the producer-gas power plants of the country with the idea of ascertaining as far as possible the exact situation from the owners and operators. No selection was made of the plants to be visited. In the list are producers from fourteen manufacturers. The territory visited was from Maine to Central Nebraska. The data presented in the following table are from the statements of the owners or operators, and the notes which follow under the headings of "Difficulties" and "Remarks" are from the same source, or from my own observation.

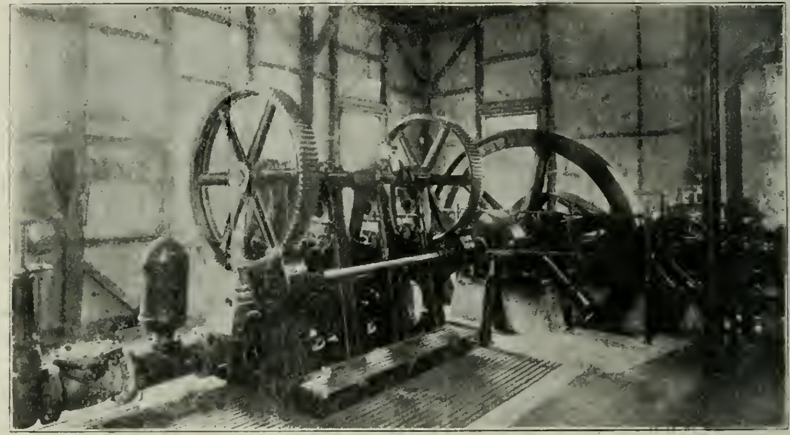


Fig. 27.
Typical Suction Gas Producer Installation with Direct Connected Pump for Municipal Water Works.

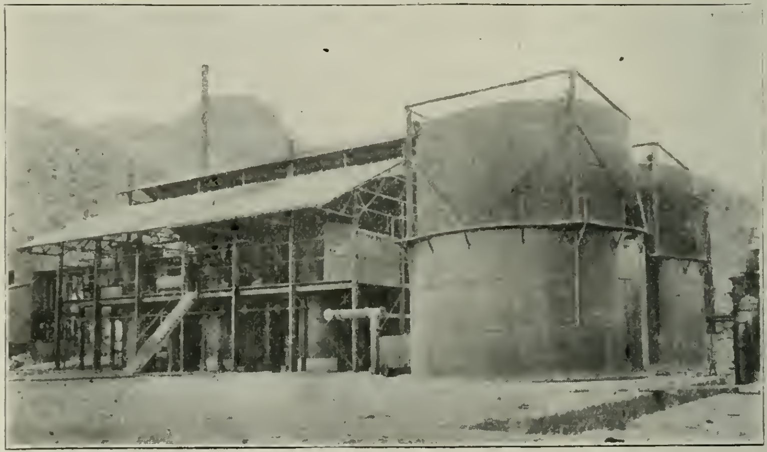


Fig. 28.
Up-to-date Gas Producer Installation for Central Power Station Manufactured by Power & Mining Machinery Co.

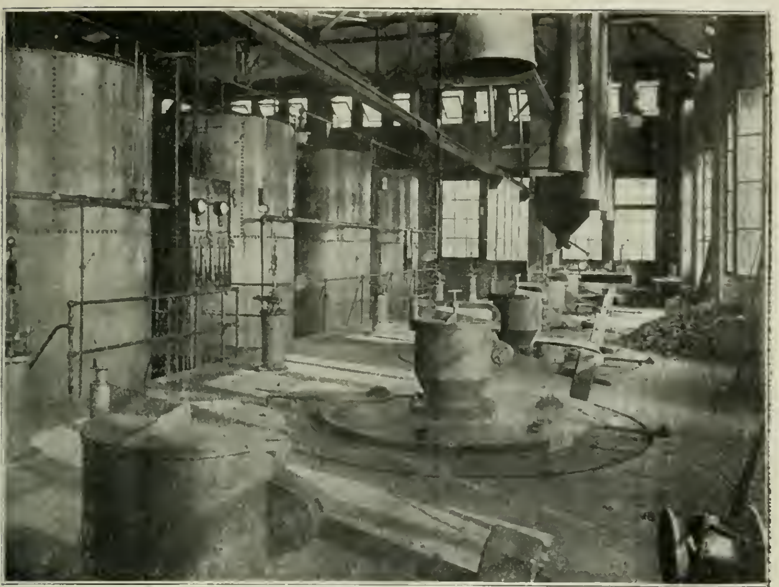


Fig. 29.

Typical Operating Floor of Producer Gas Central Power Station for Street Railway Service, Manufactured by R. D. Wood & Company.

PLANT NO. 1.

Difficulties.—Plant absolutely worthless for intermittent service required by a gristmill run on the basis of this one.

Remarks.—The owner of the mill believes that he was worked by the agent by misrepresentations in buying the plant. The agent claimed that this plant would do everything exactly as he desired, i. e. it would be just the plant for variable demands; it would fill the bill exactly.

He believes thoroughly in this type of power for continuous, or for ten hour service daily, but finds it worthless for his use. He fought payment a long time but finally settled rather than have a lawsuit. He wants to get rid of the plant, and says that he has written the company many times trying to get them to take it off his hands.

He believed that the company hasn't men competent to install and operate plants. This was illustrated by the use of a wooden barrel for an exhaust drum: Result, barrel caught fire and half of it was burned up. It as only by good luck that the gristmill was not burned down. He showed this to the erecting man (who was then putting in the waterworks plant) but he "didn't care a ——!"

He said the company would have had a chance to install a plant in the neighboring town, if they could have started his without difficulty, but it took them so long to get his to running properly that the other people would have nothing to do with it. He believes that the company is hurting itself seriously by its methods.

PLANT NO. 2.

Difficulties.—Serious clinkering; producer well filled with clinkers after each day's run; large quantities of clinkers taken out every night; operator says he has a "fierce" time. He says that he sometimes gets coal that does not clinker badly. The plant fails to respond to the variable load demands so the operator has to help out with city gas.

Remarks.—The operator thinks the plant uses 30 H. P. when running full. This load comes on suddenly at times. He thinks the engine can do the business, but does not get gas enough from the producer. Somebody has told him that the producer was too small for the work demanded of it.

During my visit the operator kept jumping constantly from the air compressor to the city gas valve admitting more or less gas to the engine as the occasion required. He also had to vary his air supply continually to secure proper mixture. He practically had to nurse the plant along at all times.

I noted that he knew nothing of the theory of the working of the plant, and further that he knew nothing of the construction or arrangement. The inlet air valves to the producer were both closed so the engine could draw little air or steam through the producer. He did not know that he had any steam, and if he did have he did not know where it went to or where it was supposed to go. He usually has to shut down at noon in order to blow his fires to secure gas for the afternoon run. This blowing process requires about an hour.

My impression was that the engine was actually running on city gas—was doing the work required and incidentally "dragging" the producer besides. I think the producer was furnishing very little, if any, CO. The engine must have been pulling some air through the producer, probably through cracks around the doors and plugs, but it was not getting its air through the proper channel. I believe little or no steam was getting into the fires. The producer was hot, too hot.

The indications were that the producer was well filled with clinkers at the time of my visit.

Last month's city gas bill would tend to verify the above conclusions as it amounted to $60, according to the operator. He claimed that there had been months when the city gas bill was only about $3. He said he feared the action of the "boss" when he found what the bill was this month.

The plant was installed either in December, 1905, or January, 1906. The present man had been operating it seven months. He claims that the plant was put in with the understanding that it would cost only $1.50 per day to operate it, as the man who attended it could work on other things, etc. He claims that at the present time it is costing per day:

$1.50 for coal,
2.00 for gas,
2.50 for service.

I believe that the price for coal and operators' services are somewhat pushed in this estimate.

The engine had been running for three years, and he said: "Without even having a screwdriver put to it." It seemed to be operating fairly well, although with the erratic conditions it was somewhat difficult to determine this point.

The producer is charged with fuel three times every day—morning, noon, and night.

The foreman of the plant seemed well satisfied with the uniformity in the running of the plant as far as he had noticed. The owner of the plant was not there.

PLANT NO. 3.

Difficulties.—Claimed none; plant running very steadily during my visit; I understood there was some difficulty when the plant was first started two years before, but the present operator, who had been with the plant about one year, claimed to have experienced no difficulty whatever.

Remarks.—The operator reported that he found considerable difference in the various loads of coal delivered to the plant, one load causing no trouble from clinkers, and the next load giving considerable trouble. He regarded the producer too small for the engine and the load carried. He felt that the producer should be large enough to require charging only every two hours—without letting the bed get low. He claimed that there had been no shut-downs of the shop on account of the producer plant during his year of service. One of the office force whom I interviewed seemed perfectly satisfied with the operation of the plant.

PLANT NO. 4.

Difficulties.—None at time of visit although there was some difficulty from clinkers when the plant was first installed.

Remarks.—The plant had been in ten months. The owner wanted a producer plant, but wanted it installed without any cost to himself until it had been run thirty days. He says that most of the companies wanted one-third on contract, one-third on shipping, and one-third when installed, without even proving the possibility of running successfully.

He says that he finally found a company that would be glad to install the plant without a cent until after thirty days of successful running. He took up the offer at once and the plant proved entirely satisfactory for thirty days.

About ten days after the contract period, i. e., forty days from the time of installation, they had considerable trouble. He found that the operator sent by the producer company knew no better what the trouble was than his own man. Finally they found that the trouble was caused by a bridge of clinkers. After that experience the plant ran very satisfactorily. The owner is very enthusiastic about the plant and would not do without it. He claimed that the plant cost him 35c per day of ten hours as against $2.80 per day with city gas.

PLANT NO. 5.

Difficulties.—Said to be with engine and generator rather than with the producer. The engine is undoubtedly too light for the load carried, and its construction was not suitable for producer gas work which accounts for the change of engines which was being made at the time of my visit.

City gas is used in starting the engine, and in case of emergency, to help out the producer. With the new engine it is thought that the use of city gas will not be necessary.

Remarks.—If the present installation turns out as expected the manager says he will increase the capacity as rapidly as possible.

They want to use bituminous coal if possible, and would like a producer for this purpose.

The fuel used for this plant at the time of my visit consisted of one part Pennsylvania buckwheat anthracite and two parts semi-anthracite from Bernice.

The engineer claimed that he could regulate the height of the clinker bed at will with this combination of fuels.

Another semi-anthracite coal which has been used to some extent is known as Spadra.

When I visited the plant in the evening, a limited amount of city gas was being used to keep the engine up to the full steady load.

PLANT NO. 6.

Difficulties.—None, if the plant is properly handled, and supplied with proper coal.

Remarks.—The owner claims that the success of the plant depends entirely upon the method of handling and the coal used. He says the producer company knows nothing about running the plant. His own company had to study the plant and had to run it. They got no help from the producer company. He further says that other plants of the same make have failed simply because of lack of ability and intelligence on the part of both the people using the plant and the producer people. He thinks he could make a great thing out of the producer business. He is exceedingly enthusiastic over the proposition and thinks his producer installation is "just

O. K." He does not want anything better—it just suits him. He can't speak too highly of the plant, but does not feel that any credit is due the producer people. The credit belongs to himself and his company who run the business and are interested in having things right.

The owner wants either Nottingham or Plymouth Pennsylvania anthracite, No. 1 pea. Must have one or both of these for good results. Can run on other coals but has trouble with clinkers, and more work is required in operating.

The installation impressed me as being excellent. The room was clean and well cared for.

I was told that the total water cost for this plant was equal to the coal cost

PLANT NO. 7.

Difficulties.—None; have to look out for tar in the valve stem. No trouble with the producer at all; had a little trouble with the engine just at first.

Remarks.—The owner claimed that 10 H. P. on gasoline cost $1.20 per day of ten hours. He claimed that this plant using only 40 to 50 H. P. saves him $1,500 per year over any other fuel. He figures that it costs him a bit over a dollar per day of ten hours for 50 H. P. He says his average cost is 80 or 90c per day.

The plant was put in in June, 1905. He says he would not take $10,000 for it if he could not get another like it.

He thinks little of the ability of the man sent out by the producer company to install the plant. There were two or three men in the plant at the time of my visit who could operate it with perfect ease.

It was running very nicely during my visit and was not tampered with in any way. The 14-horse-power planer was suddenly thrown on. The engine slowed down a bit but picked the load up well.

The engine is started by compressed air. The gauge registered 110 at the time of my visit.

City gas is connected for use in time of emergency, although they claim that it has not been turned on for months.

I was told that the installation of this plant has brought the insurance way down.

PLANT NO. 8.

Difficulties.—"All kinds"—plant not running. Runs at times, not at others. Clinkers badly, and the operator finds it impossible to get the blast of steam through. The operator seemed to think that with a clean producer (was just cleaning out) and with new coal they could probably handle the plant without further trouble. Up to the present time (the plant had been installed eight months) it had done little.

The engine igniters had to be filed every day. They seemed to be very soft, and looked pounded as though the spring were too strong.

They had smashed six inlet valves during the eight months.

The engines are of the gasoline type, converted.

Remarks.—The operator claims that he can start the plant in twenty or thirty minutes at times, but not at all others. The two adjoining towns were without water for three days at one time. The water works had an old steam plant but this was broken down. It required five hours to start the producer plant. As the operator says, "They would have been in a fix if fire had broken out."

The operator seemed to believe producer-gas to be the coming power, but admitted that he did not know how to handle it at present. He seemed to think that the producer company did not know much more about it, as the man sent to erect the plant had difficulty in operating it. "Get the money seems to be the principle of the manufacturers." He said they did not seem to have competent men to put up and start the plant. The men who erected this plant were young fellows, twenty or twenty-two years old, with "swelled heads." The operator said that he made out that one of the men sent to erect the plant must be at least 106 years old, if he could judge by his experience, as he claimed to have been in every line of business from hotel clerk to erecting gas producers, including four years in college.

My own impression in this case and in that of Plant No. 1 led me to believe that the manufacturers were not giving proper attention to their plants. As soon as they secure the money they seem to let things run along without any further attention.

PLANT NO. 9.

Difficulties.—The engineer claimed none at the present time but stated that as this was an early type of producer he found it necessary to make several minor changes in the steam supply pipe, etc., to secure good operation.

Remarks.—Minor fluctuations in the speed of the engine were noted. The engineer claimed that this occurred only when the engine was under heavy load. My impression at the time was that these fluctuations were due to variations in the quality of the gas. They were not, however, serious or frequent.

Electric lights were thrown on and off without apparent fluctuations of the engine. The light was fair in quality and steadiness.

PLANT NO. 10.

Difficulties.—None.

Remarks.—This plant had been running since February, 1906, and no shut-downs had been made on account of any failure in the operation of the plant. They had been troubled with clinkers only once. The owner advises the thorough cleaning out of the generator every three months. He said that without counting the cost of water in either case, steam power costs him $100 per month, while the cost of operating the present plant is less than $25 per month. He had not paid a cent for repairs.

The large producer plant was bought in order to have sufficient power for the second engine, if desired later.

He stated that he had operated many steam plants in the old country and knows the steam proposition thoroughly. He is exceedingly enthusiastic regarding the operation of his producer plant. He said that every manufacturing establishment in the vicinity has watched the producer installation very closely, believing it to be a foolish venture, but now others are thinking of making similar installations. The men in the shop are constantly being asked by outsiders if they haven't had to shut down yet.

There was no apparent noise of the exhaust in approaching the plant. An exhaust pit is used. There was no more noise than with the ordinary steam plant of the same size, and nothing visible such as smoke, steam, or chimneys. Upon approaching the plant I was very much in doubt whether the producer was running. The installation is very neat. The plant was not touched during my visit and was running very well.

PLANT NO. 11.

Difficulties.—None.

Remarks.—The plant had been operating one year. The engineer claims that during the year they have been shut down only three hours which was due to a water leak in the engine cylinder head.

The engineer has entire charge of all machinery, etc., including the sewing-machines. He employs a boy who attends to the packing and shipping of goods, and feeds the fuel into the producer and pokes the fire occasionally.

They intend to enlarge the plant to 150 H. P.

PLANT NO. 12

Difficulties.—The operator claims none. He likes the plant and is anxious to get all the information possible in order to equip himself for the proper handling of such plants. I was much pleased with his appearance, ability, and enthusiasm.

Remarks.—The fuel used, anthracite No. 1 pea, looked dull and poor but seemed to work well. There was also a pile of bright anthracite. The operator claimed that the mixture of these two coals caused serious clinkering

He also claimed that the re-use of partially burned coal from the generator produces clinkers.

PLANT NO. 13.

Remarks.—Engine reported as "N. G." The plant was installed in January, 1906, ran about half of the time for four months and then the engine broke down and has not run since. At the time of my visit the power was furnished by a steam engine. They may possibly get back to gas if they can find a *good* gas engine.

The engine was not designed for producer-gas work. In fact, its only qualification, in my opinion, was its low cost.

The use of such engines is a serious drawback to the success of producer installation.

PLANT NO. 14.

Remarks.—In recent installations for a guaranteed service of twenty-four hours per day, this producer company is putting in two gas generators as they find it necessary to draw the fires from one generator each Sunday, that is, once a week.

PLANT NO. 15.

Remarks.—Plant had not been in operation for several weeks.

Several men from the producer company had just over-hauled the plant. It had been in only a short time but the producer was being relined. New bearings were being put in for the crank shaft, etc.

One of the men remarked that the plant was in terrible shape and whoever had charge of it ought to be lynched. Inquiry from a "native" regarding the operator of the plant indicated that it is the usual story of a poor man more than a poor machine.

He was described as "no good and very fond of his 'jag'." The report was that his saloon bill was about $40 per month—that he was in the habit of getting a "jag on" several times a week, leaving the operation of the plant to a helper who knew little or nothing of its requirements.

PLANT NO. 16.

Remarks.—Plant not running when visited. It is a new plant erected in the spring of 1906 and presented an excellent appearance. The engineer stated that the company that installed the plant never instructed any man definitely about running it. He finds himself able to run it at times, but not at others. He never knows whether he is to get gas of good quality or not. After it is once started he says it runs well but, as he put it, the fact is that he knows nothing about running it, and has never been shown. He seemed to be an able, intelligent man and desired instructions.

The man who erected the plant is reported to have gone around the corner of the building every time he consulted his blue prints for fear the engineer and others would see them and gain some knowledge of the construction of the plant. At other times the blue-prints were kept locked up. I was informed that an operator of a similar plant in another part of the country was sent to this plant later and operated it with no difficulty.

At the time of my visit the water for the town was pumped by a gasoline engine which the engineer had no trouble in operating. Fortunately the town had never had electric lights, consequently did not seriously miss them.

Compressed air was used for starting the producer-gas engine. This air was pumped by the gasoline engine which at that time was pumping water, but in regular operation the air is compressed during the run, and kept in reserve.

Blast for starting the producer was furnished by a small blower, driven by a small gasoline engine installed for the purpose.

PLANT NO. 17.

Remarks.—The producer operator whom I saw is a regular "Bowery" type. His whole idea of the plant is centered in the ease of operation. He said he was formerly a steam engineer. He likes the producer "all right, all right," as he can sleep and let it run itself, and can go out of doors when he pleases "to get a breath of air and watch the people." He says he likes ease and rest.

He had just succeeded in smashing two holes in the engine cylinder-head so that the plant was shut down for repairs on the engine. He claimed to run from 120 to 125 hours without shutting down, and then to take about six hours for cleaning, etc.

The producer had been installed about two years; the present engine about four months. The plant was provided with the Combustion Utilities Company's process. This had been in operation only four weeks. The producer operator liked this new process because he could sleep for six hours without bothering his head about charging the producer, whereas, with the ordinary method he had to charge every two hours. "Now I fills her up chuck, den I takes me nap fur five or six hours, see? Gas producers fur mine, every time, you bet."

PLANT NO. 18.

Difficulties.—All kinds at first; changes have been made ever since the plant was installed; a new 2 or 2½ inch top plate was put on in place of the ⅝ inch plate used by the manufacturers.

The superintendent claimed the vaporizer never made steam so he introduced a steam pipe from the boilers to help out, etc., etc.

The plant was shut down at the time of my visit on account of clinkers. The operators must have taken out two bushels of clinkers in large masses. The superintendent claimed that they had had no such trouble in three months—as his former operator handled the plant well, but they had to let him out on account of drunkenness. It seemed that during the last days of the service of the former operator the plant was not properly cleaned and the clinkers began to accumulate.

Remarks.—Had difficulty in getting permission to see the plant. The superintendent was very suspicious but finally consented to my going in with him.

He said that the gas producer company showed no interest in the plant whatever; he would not have the plant if it were out, but as long as he has already put it in, he is making the best of it. He is changing it in every way possible, and claims that it has been running well for three months. The former operator of the plant was paid $1.65 per day.

The superintendent believes in producer-gas plants, but not in the one installed by this company. I was unable to learn of any other installation of this make of producer.

PLANT NO. 19.

Difficulties.—They burn out the "bell" or "thimble" about every six weeks. The last period was only one month. The producer was shut down during my visit on this account. The engine was running on city gas. The cast-iron thimble actually melts, which indicates a very high temperature and probable lack of moisture in operating the producer. As the plant has its own foundry they are able to cast their own thimbles and keep extra ones on hand.

Remarks.—They claim to have no trouble from clinkers and never draw the fires save when the thimbles burn out.

The engine ran poorly on city gas; it back-fired badly and the speed seemed low. The operator claimed that the speed was always fifty revolutions lower on city gas than on producer gas.

The plant began operating, I believe, in February, 1906.

PLANT NO. 20.

Difficulties.—Clinkers. Ran nicely on charcoal costing $11 per ton but failed on coal costing from $4 to $5 per ton. The superintendent said the engine was "O. K." but the producer "N. G." The plant had been in one and a half years but had not been run for two months. They claim to have received no assistance from the firm save a little from one of the men who erected the plant.

They had an operator who could handle the plant very successfully but he left two months before my visit and they had not been able to run since. After he left their employ he came back once or twice and ran the plant successfully but the other operator could not handle it. It clinkered badly after two or three days so that it was impossible to run.

They claim that at one period the plant run successfully without cleaning for eleven hours per day for three weeks, but upon investigation they found that the operator had used two-thirds charcoal.

They say that the failure of this plant has killed the producer business in this region for this producer company, and has seriously hurt it for all others.

I was told by disinterested parties that the chief difficulty with this plant is due to the fact that the owners will pay only $40 per month for a man to run the whole plant, and won't pay anybody to put it into proper shape for successful operation.

A 125 H. P. motor was operating the plant.

PLANT NO. 21.

Remarks.—This plant had been running about nine months. It was equipped with the apparatus of the Combustion Utilities Company.

The plant is reported to work splendidly since the above equipment was added although prior to this addition some back firing and pre-ignition were experienced.

According to the Superintendent, the company is greatly pleased with the results of the plant at present. Previous to the addition of the equipment of the Combustion Utilities Company, the compression carried by the engine was 120 lbs. At the present time they are carrying about 200 pounds.

PLANT NO. 22.

Difficulties.—Plant seemed to run fairly well. According to the statement of the owner there was some trouble at first. They have some trouble with the magneto, the spark being cut out at times. This happened while I was present when they shut down the plant.

They have some trouble with poor gas occasionally—some weeks there are no shut-downs while at other times there will be two or three in one week. These are, however, of short duration.

Occasionally they have been slightly troubled with clinkers.

PLANT NO. 23.

Difficulties.—Plant was installed about Christmas, 1905. It was three months before they could operate it; clinkered badly. Top of generators burned out and had to be rebuilt.

Had more or less difficulty with the engine also. The fly-wheel is 180 pounds out of balance. They claim it is no "fault" of the manufacturers that the plant runs at all.

Remarks.—The engine is located about 135 feet from the producer.

A 125-horse-power producer was installed at first. A second and larger producer had to be installed so that they could be worked alternately if desired. They were both running at the time of my visit.

For the first three months the plant resulted in heavy loss to the company, but the manager believed that they would make it up by the end of twelve months due to the economy of the plant. He says they would not install such a plant if they had to depend upon it, but they can change to steam in six hours time if driven to it. They usually start the plant by steam until it is in full operation.

They find that Lehigh Valley coal mixed with other coal clinkers badly.

PLANT NO. 24.

Difficulties.—Troubles at first; producer was too small; had to get larger producer; the valve cams were wrong; manufacturers would not show them anything.

The producer company claimed that all the troubles were due to the fact that a steam engineer was in charge of the plant. The owner was satisfied that this was not the case, so he fought it out—got a larger producer, reground the cams, had the valves reset, and now has the plant running in excellent condition.

Remarks.—This plant was installed in January, 1906. A long time was spent looking into the matter. Minneapolis, Chicago, Philadelphia, etc., were visited in order to size up various plants. The engine was what decided the choice. Don't like vertical engines as they want an engine where they can put their hands on any part of it.

Some difficulty was experienced with magnetos.

They have had some trouble caused by the stripping of the thread of the engine valve stems. This happened while I was present.

They are running the exhaust into the fire box of the vertical boiler for heating water and also doing away with the exhaust noise.

The engine was belted to a 150 K. W. electric generator.

They handle the clinkers in the producer rather successfully with bent pokers. They have had to put extra holes in the producer for this purpose.

The plant is very neat and apparently well understood.

PLANT NO. 25.

Difficulties.—A good deal of trouble by back-firing. At the time of my visit the electric generator was sparking seriously, and burned out before I left the plant.

Remarks.—On the whole the company seemed to be fairly well pleased with the results.

The method of handling the producer was wasteful of fuel as about one-third of the coal charged to the producer was taken out unburned in the ash. This mixture of ashes and coal was used on the walks about the plant.

PLANT NO. 26.

Difficulties.—All kinds with the old type producer which is now being torn down; no difficulty experienced with the new type now in operation. This new producer is liked very much by the engineer.

Remarks.—A second producer is to be erected at once.

No gas holder; automatic steam control. Engineer claimed it worked well. Carries steam pressure in auxiliary boiler 50 to 80 pounds.

The fires had not been drawn since the new plant was put in operation five months before. The engineer thinks the difficulties in most cases are due to the operator and methods used, rather than to the plants themselves. He believes in the plant thoroughly; is interested and wants to learn.

The engine exhaust is run into a pit filled with broken rock; the noise is hardly noticeable.

PLANT NO. 27.

Difficulties.—None now; what they did have, the owner stated, were due to careless operating rather than inherent faults with the plant.

Remarks.—This plant had been in operation about 2½ years.

Besides the gas used for power this plant also furnishes the gas for heating 150 irons in the ironing and pressing room. The heat is found to be steady and very satisfactory. They formerly used city gas but find the present arrangement far more economical. They still have the city gas connections for the irons in the same pipe system but have no occasion to use it.

They purify the circulating water and use it in another portion of the work.

I was told that cheaper fuel is used in the producer than under the steam boilers

At present they are laying the foundation for the installation of another engine in addition to the present one.

The owner stated that although he regards the initial cost of such a plant as higher than the cost of a corresponding boiler plant, there is, in his opinion, economy in additions to the plant, that is, producers can be added without adding extra scrubbers, holders, etc., and thus have a reserve plant for less cost than a reserve boiler plant.

No odor of gas was perceptible in the ironing room. This gas is supplied by pumping; a rotary blower is used for this purpose; the pressure is low. The gas burned with a steady blue flame.

PLANT NO. 28.

Difficulties.—Slight at first with mixtures, etc., but none now. Plant is very satisfactory.

Remarks.—The plant has been running over a year. The engine is directly connected to 150 K. W. Crocker-Wheeler generator.

They claim to have had no trouble from the action of the sulphur. I noted occasional back firing in one end of the cylinder.

The exhaust is used for heating feed water for the steam plant. The gas engine is run in parallel with the steam engine.

No exhaust noise; they use large exhaust ports of special form making the pipe connections "flaring" in such manner as to accommodate the expansion of the gas.

The producer operator receives 20c per hour.

PLANT NO. 29.

Difficulties.—None with producer; none with engine, mentioned, although the opinion seemed to be that some of the engines were not adapted to the work demanded of them.

Remarks.—At the time of my visit these producers had been installed nearly 7½ years. One had not had the fires drawn for six years and ten months. The fire was drawn then in order to put a new top on the producer. The lining of the producer was found in perfect condition, and not a brick was renewed. It had been five years since the fire was drawn in the second producer and the engineer stated that he did not know when it would be drawn, as there was no reason for doing it.

The economizer tubes filled after a time so it has been customary to change these about every two years. The old tubes are cleaned and replaced two years later.

Engine (a) had been installed two years, and had given entire satisfaction. It was running well when I visited the plant.

The two engines (b) had been in over seven years. They were installed with the original plant. The engineer objects to the hit and miss governor on engines.

Engines (c). Two of these engines had been in six years and one five years. These were running satisfactorily while I was there.

Engines (d) and (e) are about 1800 feet from the producer plant. Engine (d) seemed to be helped out occasionally by city gas—*"only occasionally,"* I was given to understand, but engine (e) was run almost entirely by city gas.

The engineer was greatly pleased with the producer plant. He claimed that he experienced no difficulty with the producers and said that they gave excellent satisfaction. One producer was operated with automatic feed, but the other was not.

PLANT NO. 30.

Remarks.—Only one engine was running during my visit; this seemed to be very steady in its operation.

Tar extractors were installed with this plant for operation in case bituminous coal should be used.

PLANT NO. 31.

Difficulties.—They have had some trouble from clinkers. Also, I believe, some trouble from lamp-black.

Remarks.—The superintendent did not feel absolutely sure about the power. He seemed to be well satisfied with the plant on the whole, but did not feel that it is absolutely reliable under all conditions. He was somewhat doubtful whether, in increasing the capacity of the power plant, to add more producer gas units or to put in a steam plant to supplement the present gas plant. He seemed inclined to the additional producer gas units provided he became positive of the absolute reliability of such power for continuous service, twenty-four hours per day.

The plant was running well at the time of my visit.

PLANT NO. 32.

Remarks.—Most of the water gas (200 B. t. u.) was used for forges, etc., power being a secondary matter—a by-product as it were.

The producer (air), gas generated, was of about 90 B. t. u. heat value. The gas supplied to the engines is a mixture of the water and air gas in such proportions that its heat value is in the neighborhood of 115 to 130 B. t. u. per cubic foot.

The manager likes the plant well enough but feels that perhaps they could get more out of it than they do.

PLANT NO. 33.

Remarks.—The coal used was Pocahontas which is delivered at the central station and the various plants are supplied with the mixture as it comes from the central station. Owing to the repeated handling the coal is reduced to a very fine condition.

The engine that was running while I was at the plant was pounding slightly. The engineer reported that they had broken exhaust levers occasionally, due entirely to the carelessness of the operator.

34,000 cubic feet of water were used by the plant per day. Water was taken from the near-by brook instead of from the city service. The producer man was paid $16 per week.

In operating this plant at the present rate, water gas is made only three times per day, and then only for two or three minutes at a time—long enough to fill the holder. The water gas is by by-passed and mixed with the producer gas. A small portion only of the former was used.

The people in the vicinity objected to the noise of the exhaust. Several devices had been used to reduce this noise. At the time of my visit the plant was using a pit filled with broken rock which seemed fairly satisfactory.

The engineer says that the men about the plant were greatly pleased with the producer at first—as with a new toy—but after the novelty wears off their interest flags. He says that the plant must be looked after and that there is a tendency on the part of the men to neglect it.

They have had occasional pre-ignitions, and back-firing but these have not been serious.

*For detailed information regarding the economical operation of the plants designated Nos. 30 and 33 the reader is referred to a paper entitled "Gas Engines" read before the American Street & Interurban Railway Engineers' Association, at Columbus, Ohio, in October, 1906, by Mr. Paul Winsor, Chief Engineer Motive Power and Rolling Stock, Boston Elevated Railway Company.

PLANT NO. 34.

Remarks.—The producer manufacturers have not been called upon for any assistance since the plant was installed in 1900, but several changes have been made in the plant which have proved beneficial.

The gas producer installation has been a process of development with this company, the original plant having been installed in 1900. One exhauster was run at that time by steam power and the other by a gas engine. After watching this gas engine for a time it was decided to try gas for power purposes. A tandem engine with rotary valves like those of a Corliss steam engine was installed. Grit would lift these valves from their seats and the engine gave serious trouble. Finally another type of engine was tried, and as it worked from the start with no difficulty, four additional engines of this make had been installed. They were expecting to install, last fall, additional engines of the horizontal, double-acting type.

Straight water gas is used in many portions of the plant, but when low heats are required a mixture of 4½ parts producer gas (air gas) to one part water gas is used, giving a gas with a heat value of about 135 British thermal units per cubic foot. For the engines six parts of air gas to one of water gas are used, giving a gas of about 115 B. t. u. per cubic foot.

Gas power has proved exceptionally economical for this plant as most of the producer gas which had to be made was wasted before the installation of the engines.

The company believes thoroughly in this system of power and more and more or the plant is being supplied with gas power.

The plant requires proper care which necessitates a good grade of men. For this reason the representative whom I saw believes that there is better economy in labor in a central power plant rather than in separate engine installations in various parts of the factory.

Every Sunday one engine is thoroughly cleaned and the inlet valves and mixing chambers in the others receive attention.

The deductions made from these visits are:

1. The plants as a whole are giving remarkable satisfaction considering the very brief period of development that has passed since the introduction of this type of power.

2. The most serious difficulty seems to arise from the lack of competent operators to run the plants rather than from inherent troubles with the plants themselves.

3. Incompetent salesmen are undoubtedly to blame for serious misrepresentations and misunderstandings.

4. The policy of some manufacturers of entirely neglecting plants after they are installed and paid for has not been farsighted, nor has the failure to give the purchaser of a plant, or the operator, full information regarding the construction and methods of operating.

The situation as a whole at the present time seems to be very favorable for the producer-gas plant, both as to cost of installation, operation, and maintenance and as to reliability. With the additional impetus given by the successful demonstration at the Government Fuel Testing Plant, that the bituminous coals, lignites, and peats can be utilized with great economy in these plants, the increase in the introduction of this form of power within the next few years may surpass even the most sanguine hopes of the manufacturers.

CENTRALIZATION OF POWER DEVELOPMENT AND DISTRIBUTION.

The rapid strides in electrical development will be greatly increased within the next few years by the reduction in the cost of power production made possible by the introduction of the gas producer. It would seem ridiculous to predict the immediate doom of the steam locomotive, yet one of the officials of the New York Central Railroad has publicly stated that in his opinion there will be no steam locomotives operating on the New York Central road in ten years. Already the "New York Central" has substituted electric power on its lines from New York City to a point about forty miles from the Grand Central station, and it is rumored that before long electric trains will be running from

New York to Buffalo. The "Pennsylvania" is to do away with the steam locomotive between Atlantic City and Philadelphia, and the "New York, New Haven & Hartford" is following the same tendency by running its trains from Stamford, Conn., to New York City by electric power.

These rapid changes are leading to one end—*The Centralization of Power Development and Distribution.* Now that it is commercially possible to transmit electrical power for distances of 250 or more miles, a central plant could distribute such electric current for a distance of 500 miles, i. e.,—250 miles either side of the plant, thus covering an area of almost 200,000 square miles—an area nearly four times the size of the state of Illinois. The logical location of such a plant is at or near the mines. With ten or twelve of these great central plants located at the various mine centers, the great railroads of the United States can send their trains speeding from the Atlantic to the Pacific coast; and the passengers, as well as the towns, through which the trains pass, will be entirely freed from the usual annoyance of smoke and cinders, and the disastrous fires caused by sparks from locomotives will be a thing of the past.

In conclusion I desire to express my appreciation of the kindness of the Power & Mining Machinery Co., R. D. Wood & Co., Wile Power Gas Co., Olds Gas-power Co., The Smith Gas Power Co., The Minneapolis Steel & Machinery Co., The Westinghouse Co., and the Otto Gas Engine Works, in supplying valuable data and photographs; and I also wish to thank my assistants at the Fuel Testing Plant for valuable services rendered in preparing the numerous tables and charts.

DISCUSSION.

President Abbott: I appreciate the embarrassing position in which the gas engine expert is placed when he attempts to discuss the gas engine proposition together with the steam proposition and try to be fair to the steam engine, but I think that Professor Fernald has succeeded in this.

Mr. C. E. Sargent, M.W.S.E.: I have been very much interested in listening to the presentation of this paper.

For several years I have been trying to impress upon the engineers of this country, and especially the engineers of Chicago, the possibilities of the gas engine and producer, but being "from Missouri" they have always wanted to be shown. The gas engine and producer have come to stay and the results obtained from such a combination are in many cases exceeding our anticipations.

There is one statement in this paper upon which I want a little more information before I can entirely agree with the author; and that is that as gas engines increase in size we may expect higher efficiencies, just as we get higher efficiencies in steam engines as the cylinders increase in volume. Of course, in steam engines in which the size of cylinders is practically unlimited our volume increases as the cube, while the surfaces where condensation takes place only increases as the square of the dimensions. It would seem that the same rule would hold good with internal combustion enpines, but as a matter of fact, as cylinders get larger the piston rods and valves must be water-jacketed so that the relative cooling surface of the burning charge increases rather than diminishes.

A properly designed single-acting engine, for this reason, should give a higher thermal efficiency than a double-acting engine, and we believe that tests will corroborate this statement. Of course, the gas engine is becoming more efficient as the compression is increased and the surface during inflammation reduced, but I do not believe that the experience of the manufacturers of large gas engines leads them to believe that the efficiency of the double-acting internal combustion engine is going to increase as rapidly as the steam engine, as the sizes increase. If I am mistaken I would like to be set right as I am very much interested in the possibilities of large gas engines.

Mr. H. I. Lea: This paper is exceptionally complete, and to my mind offers but little chance for argument. I will say, however, that I consider 6 per cent depreciation, too low for general use. There are plants in which this figure is ample, but there are others in which it is very wise to allow 15 per cent for the items of interest and depreciation combined.

I do not agree with Professor Fernald in the belief that the use of low grade fuels in producer practice will necessarily involve low thermal efficiencies. It is not to be expected that the low grade fuels can be handled to advantage under the short-time allowances and other conditions imposed on the testing plant at St. Louis, but the same skill and application displayed in the St. Louis testing plant can, I have no doubt, handle the low grade fuels with thermal efficiencies as high as now obtained with high grade fuels, provided, of course, that working conditions and producer design be adapted to the particular fuels in question. As a paper, we must certainly admit that it reflects much credit on its writer.

Mr. Straub: I came here tonight simply as a guest, and my remarks would probaoly come from a prejudiced standpoint, inasmuch as I am representing a producer gas concern.

Professor Fernald's paper typifies the present standing or the present feeling of the general engineering profession toward the gas producer power installation.

In regard to Mr. Sargent's question relating to increased efficiencies in large engines, I am not going to attempt to explain why, but I will give you the actual results. On a certain large installation where there were put in 4 twin, double-action engines developing 5,400 h. p. each, those engines show a brake horse-power with 7,200 B. t. u. This is on account of smaller amount of radiating surface, among other things.

In regard to the question of depreciation in a producer gas plant as compared with a steam power plant, I know of producer gas engines which have been in operation twenty years and are still operating. The depreciation has been very slight. One plant has eighteen producers, which have been in operation since 1888, and the plant is good for another ten years. I have reports on a 4,000 h. p. producer plant in New Haven. The average amount of depreciation was $147 per annum.

I think Professor Fernald has done the engineering profession a great favor in bringing forth this paper, which is exceedingly complete.

Mr. McMynn: I feel that the gas engine has come to stay, and think that the matter of depreciation is very small as compared with the steam turbine.

Mr. H. S. Bowen, M.W.S.E.: The study of a large plant has brought out many points that are rather hazy. One was touched upon—the size of the holder for a down draft installation. It seems to be possible to figure out what the minimum size should be, but I have not been able to find any one to tell me what the *economical* size should be. Then in the large plants, another problem is the measuring of the amount of gas produced. An ordinary gas meter, or a gas meter made on the ordinary lines for a large plant, would probably be about as large as the plant itself.

The gas engine proposition in itself is open to a good many questions as to capacity, speed, wear and tear on the engine itself, etc. In studying the conditions for large units, many questions come up about which we apparently have but little data and will not have for several years or until plants have been running for some time. I think the question brought up a few moments ago, as to depreciation can be determined only after a number of years of operation.

Mr. H. B. MacFarland, M.W.S.E.: I have been much interested in this paper, and especially in its very complete presentation.

In regard to the operation and installation of power plants, perhaps one of the things that has come to my mind more forcibly than anything else, is where I have been required to give the horse power of a gas producer. Of course, we can very well establish what the horse power of a gas engine is, and yet I do not know that one can say that a gas producer can have any horse power, in that it does no work. I have considered that possibly a producer horse-power must be such as to produce gas enough to supply an engine developing a horse power. Gas engines are rated variously, as we have a statement of a gas engine running on 7,200 B. t. u. per brake horse power. I also understand that the best engine manufacturers are willing to guarantee a horse power hour on 11,000 B. t. u. and I myself have recommended at various times that the rating of a gas producer would be such that it may be determined by the development of 11,000 B. t. u. per hour.

Mr. H. I. Lea: Since this matter of employing the exhaust heat of gas engines seems to be of general interest, I will say that a method of utilization has already been devised, and will, I believe, meet with general approval. Something over a year ago I got up a very simple scheme for transferring the sensible heat from the exhaust gases to the air of the shop or of adjoining buildings. Incidentally this device actually reduces the back-pressure in the exhaust manifold when properly designed, and absolutely muffles the noise of the exhaust.

Through experiments already made, I am satisfied that from 65 to 70 per cent of the total sensible heat in the exhaust gases, can be returned as sensible heat to the air of the shops. This means a net saving of about 20 per cent of the total thermal value of the gas fed into the engine and I believe will have a very important influence in overcoming some of the objections to gas engine installations.

Referring to the matter of the size of holders required with pressure producers, I would say that, as a matter of fact, no holders are required with pressure producers operating continually. Holders were originally used on pressure producers for two reasons, viz: to provide for sudden peaks in the load and to mix the varying qualities of the gas made, before sending them on to the engine. The first of these requirements is met now in regular practice, and very successfully, by small diaphragm regulators, as well as by small float regulators. The second of these requirements is now done away with, because, with proper design and operation of blowers, we need have no such variations in the quality of gas made as to require mixing.

Among the older producer builders it was evidently not recognized that to insure a constant quality of gas, a constant ratio of steam to air must be maintined with a given fuel bed, practically regardless of the volume of gas made.

Blowers are now made that do maintain a reasonably constant ratio of steam to air in the blast, and this ratio may be readily adjusted to suit any particular fuel.

As I have shown conclusively in practice, holders on continuously operated pressure producers are no longer necessary. I would say in reply to Professor MacFarland that the rating of gas producers has not yet been standardized. In my own practice, I will give no producer a rating as to capacity, until I know the characteristics of the fuel to be used.

I would say that a reasonable guarantee on a producer plant is one in which the seller agrees, when using an engine developing a b. h. p. hr. on 12,000 B. t. u., to develop one b. h. p. hour per pound of coal of 13,500 effective B. t. u. Another reasonable proposition is to guarantee to deliver, as available energy in the gas leaving the producer, 75 per cent of the thermal value of the fuel fed into the producer.

Some one has asked whether there is any meter that will successfully handle producer gas. In reply, I would say that producer gas may be measured satisfactorily by means of Venturi and Pitot tubes, and by means of the rotary meter built on the principle of the anenometer by the Rotary Meter Co., of New York and London.

Mr. A. Bement, M.W.S.E.: We hear a great deal about the efficiency of gas engines and gas power plants, and I wish it to be understood in making these remarks that I am as favorably disposed toward the success of gas power as one can possibly be, but wish to call attention to the fact that we have too little real information. Very much is said about economical operation, and reference is usually made in this connection to heat efficiency, but it is seldom that figures are presented stating cost of power production. This is unfortunate, because the real measure of efficiency is not the proportion of heat transmitted to work, but the cost of producing a unit of power, and the fact that high heat efficiency, often quoted, is obtained with high priced coad is not always stated. There can be no advantage in a gas power plant, even if it has double the heat efficiency of a steam one, if it requires fuel costing twice as much as that which the steam plant can use.

Recently I visited a plant which builds large gas engines, and saw one of the engines of about 250 h. p. at work. Its producer was located in a large special building and required two men to operate it. The coal cost $3.90 per ton, and a steam boiler, which in itself was a considerable item of apparatus, was used to furnish steam to the producer.

At one time I sent out to various producer manufacturers, specifications covering the composition of coal used in the vicinity of Chicago, and asked them what they would guarantee to do with it in their producer. All of those who replied stated that it would be impossible to use the coal; that it was entirely unfit for producer purposes, although today in Chicago, we are burning coal screenings inferior to it under steam boilers. The trouble with these screenings from the producer standpoint was, that the coal was small in size and that the ash was high, or in other words, there was a large amount of dirt accompanying it.

It is to be regretted that the Geological Survey did not plan some tests to study the effect caused in gas production by fuel of small size and high in ash, because these are two things which make coal "poor." If it had done so, we would have had in this paper which Prof. Fernald has presented to us, items of information of much greater value than anything he has been able to offer. When this work was first taken up during the St. Louis World's Fair I made an unsuccessful effort to induce the then head of the department to undertake such experiments, and if Prof. Fernald will arrange for such investigation, he will insure that much valuable results will be obtained in the future.

Regarding the table I, with reference to what is called volatile combustible, I think that volatile matter including the volatile non-combustible also, is meant instead of only the volatile matter which is combustible.

Referring to the "Description of Illinois Coals," reference is made to "slack," and I would inquire whether any slack was actually used in the St. Louis producer, or whether the fuel referred to by this term was not regular screenings or crushed coal which may be considered as an equivalent of screenings.

Referring to the extract of paper by Mr. Stott, showing the losses in converting coal into electric energy his figures if I am not mistaken refer to New York conditions. If so, the operating cost for steam is quite high. New York City is an expensive place for labor in firing boilers, as it is done by either hand firing or else by stokers which require considerable labor, and the cost for removal of ashes is very high, amounting at the minimum to about 13 cents per ton of coal burned.

President Abbott: If I were to design and operate a power house in Alaska, I presume I would select a gas producer plant. If the power house was to be located at the mouth of a coal pit, it would be a steam plant. Somewhere between those two limits is the dividing line where it would be as economical to run one as the other, but I think you will find that point at a higher latitude than 42, that is further north than Chicago.

Mr. Bement referred to the cost of power as being the essential thing that is wanted, not relative efficiencies between types of apparatus. I think this is a vital point which our gas engines and gas producer friends have overlooked. A gas engine has a very good efficiency when run as the engine at St. Louis was at a rated load, constant load, sixty hours, etc. Suppose the engine had to start up in the morning, say at seven o'clock, run at ¼ load a few hours and then gradually pick up the load so that in three hours it had the rated load, drop off a half hour at noon, etc. I do not think the showing would be so favorable. If the gas engine man has the selection of the coal, and by right he should have, because there are a great many kinds of coal he cannot use at all, he can also make a favorable showing. But if he has to try to run on the cheapest grade of coal which comes into this market, he could not make a favorable showing; however, if he succeeded in running on that, the saving over the steam plant would be much smaller than shown.

Referring to Mr. Stott's figures. As Mr. Bement stated, his figures are probably New York costs. The coal there I presume costs $2.50 per ton; it would cost half of that here in Chicago; removing ashes probably 10c per ton; about a third of that here; cost of the plant $75.00 per h. p.; about $45.00 here, and so on down the list.

Some one made some remarks about depreciation in steam turbines. If he could see the great array of gas engines—all sorts and sizes—

which the lighting companies of the city have hauled out of basements, and sold for old iron, replacing them with steam driven electric service, he would get a different idea. I think the trouble with the gas engine people is that they are about five years too slow. If they had adopted the steam turbine on the market and manufactured the gas engine in large sizes they might have held the field, but as it is now, I think they will have to begin their work all over again. They have developed an engine which in many cases will compete with the reciprocating engine, but while they have been doing this the steam turbine has been developed and it is now as far ahead of the reciprocating engine as the reciprocating engine of today is ahead of the reciprocating engine of years ago.

Mr. A. L. Rice, M.W.S.E., (by letter): Prof. Fernald's paper is a distinct contribution to the literature of the producer gas field and the great amount of information which he has gathered and put in available form will be found of use to all who have to deal with this problem.

It seems to me that one of the most important things which the Geological Survey has accomplished in its testing plant is that mentioned in the early part of the paper, viz: the successful use of any and all kinds of bituminous coals and other fuels in a producer designed for anthracite coal without special alterations or attention. If this can be done in the pressure producer it would seem possible by proper design and management to use almost any fuel in a suction producer and, if this can be done, there seems to be no limit to the field, which the small suction producer gas engine, has in this country. The suction producer itself is an inexpensive piece of apparatus and a small gas engine is one of the cheapest installations for power that can be secured. A strong argument in favor of the gas engine plants is the minimum attendance required and if the use of cheap fuel can be combined with the cheap labor cost, small manufacturing plants and firms will have available an almost ideal source of power.

Prof. Fernald states that in comparing a steam engine plant with a gas engine plant the small size of the suction plant precludes a fair comparison and furthermore states that the large gas engine plant is likely to be less efficient than the small suction plant. This is a remarkable state of affairs and directly contrary to the condition with all other forms of power production. It is the universal rule that the larger the plant and the larger the machinery the better the efficiency which can be obtained. Of course, the difference in action of the pressure and suction producers explains this state of affairs, but it is worth while noting that the suction producer plant is no longer a small affair. Numerous plants can be found which run from 200 to 500 horse-power and, except for large central stations, this is a pretty sizeable prime mover. The fact that the gas producer has been able to use cheaper fuels than have so far been found economically available for the steam plant, is gratifying to the gas engine fraternity.

In this connection it is interesting to note that claims are being put forth in Europe that in suction producer units it has been found possible to use street refuse and garbage as fuel, mixing with this, presumably, a reasonable percentage of coal.

In regard to utilizing the exhaust heat in gas engines, Prof. Fernald states that the heating of buildings must be provided for by a plant separate from the power plant, if gas engines are used. As a matter of fact, the Admirall system of hot water heating has been adopted to take care of just this condition, water for the radiators being pumped through the jacket of the gas engine and then through a heating device which is in the nature of an open feed-water heater and taking out heat from the exhaust gases by sending the jacket water through these gases in the form of a spray. The hot water collects at the bottom of the heater and is driven through the heating pipes by a centrifugal pump.

In regard to the performance of plants, I have recently seen a plant operating on pressure producers and vertical gas engines of the 3-cylinder type, the rated capacity being 500 h. p., and when operating on 78.7 per cent load with 10 hours run and 14 hours stand-by regularly, the coal used was 1.29 lbs. per b. h. p. per hr.

Mr. W. G. Kirchoffer, M.W.S.E. (by letter): This paper is certainly of great interest to engineers, as well as to the power users, and is of great value at this time.

At De Pere, Wis., the writer had the pleasure of installing the first suction gas producer in a municipal waterworks plant in the state of Wisconsin. The plant consists of a 50 h. p. Otto suction gas producer and engine, the latter directly connected to a 500 gallon Deane triplex power pump. This plant, like some of those described by the author, gave considerable trouble on the start due to the fact that the erector did not understand connecting up the vaporizer properly, and to the lack of a power blower for the generator and a power compressor to furnish air to start the engine.

Later a 2.5 h. p. gasoline engine was installed to drive the blower and compressor; and the piping to the vaporizer was changed and the plant worked very satisfactorily thereafter.

I have noticed that nearly all manufacturers equip their producers with hand blowers, but from the experience we had at De Pere, I think it is a very poor policy.

The contractors for this plant guaranteed to develop a horse-power on 1.25 pounds of pea anthracite coal. Upon a ten hour test the consumption of coal was 1.15 pounds per b. h. p. hr., thus coming within the guarantee. At the present time I am supervising the installation of a 225 h. p. suction gas producer plant at Port Washington for the city waterworks and will soon install a 60 h. p. plant for waterworks and electric light plant at Reedsville, Wis., and a 35 h. p. plant at Juneau for the water and gas plant.

I thoroughly believe in the suction gas producer as the coming source of power and believe it will supplant steam in all places except where the power is needed only periodically.

Mr. T. E. Butterfield, Philadelphia (by letter): Prof. Fernald's article embodies the facts obtained by a perfectly honest investigator in a field which has been little explored. It is to be regretted that Congress restricted the work of the St. Louis testing plant to determining the possibility of using soft coals and lignites for producing power, for, if the prime object of the test is forgotten, some of the reported results may become misleading.
For instance, the chart Fig. 13 indicates to the superficial observer that while a producer with a rate of combustion of 6.25 lb. of coal per sq. ft. of grate per hour will have an efficiency of about 80% yet a producer with a rate of combustion of 15 lb. per sq. ft. per hour will have an efficiency of anly about 60%. Really the digerence in the results is to be ascribed entirely to the use of different grades of coal, and had no relation whatever to the rate of combustion.

In fact the relation of efficiency to rate of combustion in a gas producer is just contrary, and rises or falls as the rate of combustion is increased or decreased within the limits named, and, indeed, above the higher limit.

The rate of combustion in a blast furnace is from 50 to 100 lb. of fuel per sq. ft. of cross section, and the *relative* quality of the gas and the efficiency of conversion are both probably much higher than in the producer which Prof. Fernald tested at 6 to 16 lb. per sq. ft. per hour.

Many people are prone to didactically apply the rules of boiler practice to gas producer design, and much harm has been done by writers in periodicals with insufficient experience attempting to judge gas producers by boiler standards.

The misinterpretation of the origin of difficulties experienced with poorly designed producers operating on high ash coals, and without careful attendance, probably gave rise to this class of criticism.

The elementary mistake made is in assuming that the carbon is burned in the same manner in a producer as in a fire under a boiler. In both cases the air passing through the first few inches of fire is burned to CO_2, but here the comparison stops. There is no further consumption of carbon by air in the boiler furnace, but in the gas producer, the air enters a new stratum of the fire and consumes another portion of carbon equal to or greater than that burned in the information of CO_2.

In a carbon fire, fed by dry air, half of the carbon is burned in the formation of CO_2 near the grate, and the other half is buried in the reducing zone above the grate, and a rate of combustion in such a producer of 20 lb. of coal per sq. ft. of grate area per hour, means the same rate of combustion at the grate as in a boiler furnace, burning 10 lb. of carbon per sq. ft. of grate per hour.

In a carbon producer fed by moist air, the difference is still more striking. With perfect combustion and perfect efficiency the resulting gas is 39.8% CO, 17% H_2 and 43.2% N_2. Of the 39.8 parts of carbon burned, only 11.4 parts burn to CO_2 at the grate, while another 11.4 parts combine with this CO_2 further up in the fuel bed, and a further 17 parts combine with the oxygen liberated in decomposing the steam. This means that the actual rate of combustion at the grate is only $11.4 \div 39.8 = 0.29$ of the apparent rate of combustion found by dividing the weight of carbon consumed per hour, by the grate area.

Let us further take the average bituminous coal as fired in the producer in Prof. Fernald's tests. The composition, as given in Table I, is: Moisture 6.83, Volatile combustible 33.06, fixed carbon 49.80, ash 10.32, sulphur 2.41.

The average composition of the gas from this coal is: CO_2, 9.84, O_2, 0.04, C_2H_4, 0.18, CO, 18.28, H_2, 12.90, CH_4, 3.12, N_2, 55.60, and Tar per ton 310 lbs.

In the upper part of the producer the moisture and volatile matter is distilled from the coal with absorption of heat, leaving the fixed carbon, ash, and a small part of the sulphur, or about 60 per cent of the total weight of coal to be exposed to the chemical action of the fire. This is radically different from the boiler fire where the volatile matter is burned as fast as distilled, and greatly increases the temperature at the grate.

Sinking into the zone of reduction, the 49.80 parts of carbon lose either successively or simultaneously in the formation respectively of hydrogen from steam and carbon monoxide from carbonic acid, $0.458 \times 49.80 = 22.8$ parts and $0.096 \times 49.80 = 4.8$ parts, leaving only $0.446 \times 49.80 = 22.2$ parts of carbon to be burned in the grate fire in forming carbonic acid from air.

In other words only 44.6% of the fixed carbon in the coal, or (22.2% plus 10.3% ash equal) 32½% of the coal as fired ever reaches the true heat generating or combustion zone just above the grate, and the figure reported by Prof. Fernald of 7.64 lbs. of coal per sq. ft. of producer cross-section really corresponds more nearly with a boiler-grate rate of combustion of $7.64 \times 0.325 = 2.48$ lb. of coal per sq. ft. of grate per hour. These figures are not precise, but they show with accuracy that the terms "pounds of coal per sq. ft. of grate per hour," and "rate of combustion," have entirely different meanings when applied to boilers and gas producers.

Professor Fernald estimates that 67% of the total number of gas power plants in the United States aggregating 25% to 35% of the total horse power, are operated on anthracite coal. Of the plants he visited, 28 aggregating 2,600 or 2,700 horse power of engines were operated with anthracite producers, and only 5, aggregating 3,500 horse power of engines, were operated on soft coal. Forty per cent of the total horse-power, and eighty per cent of the total number of engines were operated from anthracite producers.

This shows that the anthracite producer is of equal or nearly equal importance with the bituminous producer; and it is to be hoped that in future government tests, the same careful study will be bestowed on the anthracite coal fields and on the anthracite producer that has been given to the bituminous coals and producers.

It would be very desirable if Prof. Fernald would describe fully the condition of the valves and cylinder of the engine after running for so many months with a gas containing such a high percentage of sulphur. Were any measurements made of the bore, of the cylinder and the diameter of the piston before and after the engine was run, and also, if the piston rings were measured, was any appreciable wear found? We notice that in the gas analysis no percentage is given for any sulphur compound, such as H_2S or H_2SO_3. Either one or the other of these must have been present in considerable amount.

CLOSURE.

Professor Fernald: I think the remarks made preceding Mr. Bement's were pretty well answered by Mr. Lee. It can certainly be said that the steam men are putting up a good fight.

The question of the cost of power was raised. In few producer gas plants can exact figures be given because the plants have not been in operation long enough. The first suction plant in this country was installed four years ago. Some pressure plants have been operating ten, fifteen, and possibly one or two for twenty years, but the majority of plants have been in service only a few years. The depreciation cost is difficult to get unless the plant has had longer service than the producer gas engine plants have had. The figures presented are simply those I have been able to get hold of. They are not presented with the idea of trying to force out the steam side, but they tend to show which way the vane is pointing.

In regard to Mr. Bement's criticism of the work done at the Testing Plant, in connection with ash, size of coal, etc., the situation is just this: The Government in making its appropriation stipulated what the work should be. We were requested to make tests on as many coals as possible and cover as large a field as we could. The coal came in such small quantities that we were restricted to one test on each fuel. Probably from now on the situation will be different. We are hoping now to make a long series of tests on one coal, providing we can get the appropriation, and the very points Mr. Bement raises will be thoroughly investigated.

Mr. Bement said further that everybody knew we could make gas out of the different coals and implied that the Government had wasted much time in demonstrating this fact. When we first started the plant I tried to get the representative of the gas producer company to use certain coals. He actually did not dare to tackle several that we had on hand, and no one knew with what success those coals could be used in the producer at the testing plant or in any other producer used for power purposes. The operator failed on the first coal that was given him because he was not used to it, and in case of the majority of coals used, the producer manufacturers did not know whether they could handle them successfully or not. It was up to us to prove that fact; that is the one thing we have had to do.

Mr. Bement's criticism is entirely just, only we have been restricted by the conditions and the newness of the problem. In regard to the question of slack: the coals indicated as such, were so listed by the Geological Survey and were sent from the mines as slack.

Both Messrs. Abbott and Bement mentioned the fact that certain coal could not be used in the gas producer. There are certain slack coals that up to the present time we have not attempted to use and I would not say we could use them but we expect to be able to do so. On the other hand, if you will notice the chart of Illinois coals, you will find several white spots, indicating that they could not make steam tests with certain coals that gave excellent results in the producer; also that they did not dare to tackle some of the lignites. It is a toss-up at the present time as there are a few coals that the gas people cannot use and a few that the steam people cannot use. A few years later it will, in my opinion, be a toss-up all on the other side.

Regarding Mr. Stott's figures, I have little to say. I should suppose they might be New York figures, except that he takes particular pains to thank various people in different sections of the United States for assisting him to get them. The steam figures were taken from his plant. They were the most reliable I could get hold of and I put them in for whatever they may be worth.

POWER WORK AS RELATED TO TELEPHONE COMMUNICATIONS.

Thomas Lambert,

Chicago Telephone Co.

Read before the Electrical Section, April 12, 1907.

There is a trait of character present in most of us which may be called a combined virtue and fault, and it is made manifest in the enthusiasm in which we view our own particular occupation. Nor would I give much thought to a man without the poesy of enthusiasm, nor pay much attention to the claims of him who did not think that his own particular business was the most important in the world. It takes them all to make the world, and right in the face of this I would tell you that no other business in the world has ever had such a phenomenal growth as the Telephone business; no other business gives such promise of future growth.

All this I say in defense of my presumption in asking you to give a few moments of your time to the subject of power as applied to telephone work. I would not care to be considered as addicted to the quotation habit; but the old adage that "One half of the world does not know how the other half lives," certainly applies to the telephone business.

If you will but step outside of your own specialty and inquire into the statistics of another's business, you are sure of being astonished at its magnitude. As a long time ago, some one asked what became of all the pins, so we can now ask, who does all the telephoning?

It is but a few years since all the telephones were operated under the local battery system and for many reasons this system is still advantageous in the smaller plants. The local battery telephone system did not rise to the dignity of having a power plant, though often having a ringing generator which was kept running continuously by means of a water or electric motor, and which constituted the power plant. The greatest portion of the power for these local battery systems is furnished by means of the primary batteries located at the several subscribers' instruments, the ringing power being furnished manually by the subscriber.

You understand that the installation of a central energy system, in place of a local battery system, is simply a financial question of engineering and maintenance. A telephone power plant, consisting of a motor generator set and a storage battery with the incidental apparatus necessary for the successful operation of the same, however small the plant, requires considerable attention of an experienced man, and this cannot be consistently added to the expense of maintenance of a small system. But as soon as the system is changed to the common battery or central energy plan, a real power plant becomes necessary, a plant representing considerable investment and requiring careful and economical operation.

In the City of Chicago alone the Chicago Telephone Company has 21 exchanges, not to mention almost as many exchanges in the suburban towns of greater or less importance. And by way of illustration, in one single exchange on the day before Christmas last year, on which day, the telephone traffic is generally the heaviest, there was a consumption of electrical energy somewhat in excess of 20 kio. for a period of one or two hours, not for illumination nor anything else but talking purposes. In the central office alone located at 100 Washington street, over 27 h. p. was used to energize the lines and instruments for talking purposes, and this continued on the occasion mentioned for a period from 2 to 3 hours.

Viewing this statement from another light, it means that no less than 10,000 people were simultaneously using telephones in a district having an area of less than one-half a square mile; 5,000 pairs of people were talking over telephones in this district, and it required 27 h. p. to furnish the energy for the service. This was the peak load, to be sure, but it illustrates the demand likely to be made upon a telephone plant at any time and for which demand or even a greater one we must be prepared at all times.

On the occasion of any great calamity, as for instance in the case of the Iroquois disaster, almost every telephone in the city was called into use, making an extraordinary demand on our sources of power. The same is true, though to a less extent, on the occassion of political elections which may have special interest attached thereto. During the evening of the recent mayorality election, we were compelled to run our apparatus and charge our storage batteries for several hours longer than usual, to care for the increased business occasioned thereby.

The variation of the peak loads for the several exchanges in a city like Chicago is rather interesting. The business districts showing the heaviest loads at 10:00 to 11:30 a. m. and at 3:00 to 4:30 p. m.; the all-night load usually falling to a small fraction of the maximum. While in the residence districts the load is indicative of the fact that the people leave home for business about 7:30 a. m. and return at about 5:00 p. m., retiring at about 10:00 p. m. The residence district often causes a peak load to occur in the early evening.

It may not be out of place here to describe briefly the simple power circuit of a central energy telephone system. We are operating our systems at a pressure of about 24 volts, kept nearly constant by means of a storage battery of 11 cells, the ampere hour capacity of which is adapted to the actual and possible demands likely to be made upon it in service. The battery is arranged in circuit so that it can be charged while at the same time being discharged to give service to the lines running out of the exchange.

The charging is effected by a suitable 30 volt shunt wound generator which is operated by either an electric motor receiving its current supply from commercial mains, or by means of a gas engine. Generally, the electric motor is directly connected with the 30 volt generator and in most of the city exchanges we have duplicate generators arranged in such a manner that the system is most flexible, either generator being capable of operation from either motor, cross connecting them by means of belts and detachable pulleys; this plan is adopted for the insurance of operation. Though as a matter of fact, it has seldom been found actually necessary to cross connect the different units.

In the Chicago Telephone Company's system one side of the battery is grounded, and to prevent the current fluctuation due to the commutation in the charging circuit from reaching the battery and consequently appearing on the telephone lines and thereby interfering with service, there is interposed a choke coil or retardation coil adapted to the capacity of the machine and its frequency of commutation. This coil acts to smooth out the current curve enabling us to charge the battery while it is being used without interfering with the traffic.

In our larger offices, the capacity of the storage battery is such that it will deliver nearly 2,000 amperes of current at 24 volts for a period of one hour, or 420 amperes for a period of 8 hours after having been fully charged. In our past experience, the highest duty imposed on any of our exchange batteries was about 750 amperes for a period of 2 to 3 hours when it fell to between 400 and 500 amperes, or nearly to the 8 hour discharge rate of the battery.

Just for a moment consider what it means to have our source of power absolutely fail during such a period as that mentioned, which is a possibility that must be taken into account. In our central office, for instance, we have two separate charging units with four sources of power, and each unit is capable of generating 650 amperes at 30 volts. Naturally we feel very secure, but suppose that all sources of power should fail at 9:00 a. m. on the day before Christmas, the batteries being fully charged at the time. In this event, the exchange would be hopelessly out of service if the power were not restored before noon.

This brings to mind the fact that it is with the telephone business, based on the nickel per call, or on the measured service basis, the same as it is with the street railway system, or an electric lighting plant, viz: a break in the service means a loss of money that can never again be regained. If the street car service is interrupted and the passengers have to walk home, the nickels for those rides can never reach the coffers of the company, and every electric lighting company is painfully aware of the fact that a stoppage of their meters is a stoppage of their revenue. So with the telephone company; messages will not keep; if the service is interrupted and other means of communication used, it is at a direct loss to the company, and worse than the immediate and pecuniary loss is the damage to reputation, often of great import, especially if franchise favors are sought. It is then a matter of the utmost importance to be as thoroughly insured as it is possible to be, as to the service for power purposes in telephone work. The telephone without the power plant is perfectly helpless and yet that is merely an auxiliary to the system, just as the telephone service itself is auxiliary to a large commercial electric lighting plant.

In addition to the storage batteries and means for charging the same, there are the various ringing generator devices, and all exchanges are in general equipped with small motors of about 1 h. p. capacity, operated from commercial mains to drive one of two ringing generators, either of which can be run as a dynamotor independently of the motor before mentioned, and from the 24 volt battery; the armatures of these machines being doubly wound to generate alternating current at about 110 volts pressure and pulsating current at about 60 volts pressure. These dynamotors, when run from the main storage battery, must be arranged in circuit with a properly designed choke coil to smooth out the effects due to the commutation of the current taken off the battery, so as not to interfere with traffic.

The alternating current is used for ringing single and 10 party lines, and the pulsating current commutated in either a positive or negative direction is used for ringing bells in the semi-selective four party line service.

The output of these machines is generally from one to two amperes. The above voltage and other specifications for the manufacture of these machines limit the voltage on the secondary side, in connection with the varying loads, to within the amount necessary for the satisfactory operation of the particular equipment used.

By way of explanation we are now adjusting the commutators that pick up the positive and negative pulsating current used on party line ringing, to such a point that in this class of service it is not commutated between the zero points, but between points 20° to 30° ahead of the zero point in the direction of rotation of the armature. This results in a correction of the current effect, otherwise caused by the inductance of the circuit, and eliminates some of the trouble due to interfering rings, by giving a slight touch of positive impulse following a longer negative or a slight touch of negative following a longer positive, in a way to neutralize in part, the lagging effect of the pulsating current.

In connection with ringing generator service, we have also to furnish a number of the smaller private branch exchanges with generator service from the main office of the district in which the branch exchange is located, and as a matter of protection, we fuse this service by means of ½ ampere fuses which we have gone to no little trouble to procure, as the ordinary ½ ampere fuses on the market were often found to carry nearly three amperes before failing.

The accidental grounding of one or two of these generator leads going to the branch exchanges would thus, when fused, result in throwing the ringing generator out of service at the circuit breaker and at the same time throwing the entire office out of ringing generator service, until this or another machine could be started up and the trouble cleared by disconnecting the grounded lines.

Generally, we also run this ringing generator service through a lamp resistence. We have adopted the Tantalum lamp for this purpose, on account of its coefficient of resistance increasing with the heating of the filament, instead of the reverse as is the condition in the carbon filament. This partially protects us from unnatural overloads on our office ringing generator due to a diminution of resistance of the line supplied through the lamp, and fed therefrom.

In connection with the ringing generator equipment, we supply other auxiliary service such as busy-back signalling, tone tests, and howler effects, and also what we denominate as ticker service used on nickel first lines to appraise the subscriber that the line is not being used.

We are now installing in our new offices, and in some of the old ones where changes have become necessary, a type of machine generator to furnish current to the amount of from 2 to 5 amperes at a pressure of 110 volts, which is used in either a positive or negative direction as the occasion may require to deposit or return coins in the nickel service. Heretofore the coin boxes have been operated by means of dry batteries located at the same exchange, the maintenance of which, has been exceedingly unsatisfactory and expensive, owing to the fact that on the failure of the voltage of the battery to come up to the proper standard every one of the hundred or more dry cells in service has to be tested, a tedious and expensive process which may occur several times during the week. By the use of these nickel deposit machines, we can keep a more uniform condition and we expect thereby to stop some of the nickel argument with the subscriber, in which doubtless many of you have participated at times.

It may be here worthy of note to say that we have had a great deal of trouble in nickel operation throughout the city, due to varying earth currents apparently dependent upon street car traffic from whose generators the current emanates.

We are gradually overcoming this by working in connection with the street car companies who readily see that this current leakage, while causing the telephone company some trouble, is costing *them* money; consequently, they have in a number of cases, increased the capacity of their return grounds to mutual advantage.

We are equipped with emergency apparatus and parts necessary for ordinary renewals which can be installed on very short notice. We did have an emergency charging outfit for use in any of our exchanges, so arranged that it could be installed on a few hours' notice and set in operation to supplant the regular apparatus in case of its failure or that of the supply of commercial power; but this apparatus was recently destroyed by fire and we are now considering a more elaborate device, which will be, quite likely a charging plant permanently mounted on an automobile for transportation to any exchange in the city or country on short notice; this to be operated by means of a gasoline engine.

Apart from the power question of the telephone service as applied directly to the lines themselves, there is also the problem of lighting the switchboard, which is very essential to the service, especially at night.

We have about half a mile of switchboard in the city alone which must be lighted in order to give satisfactory service on the telephone. This problem of lighting is really quite difficult of accomplishment, as it can come from only one source and that, above and not too far from the face of the board. Furthermore, we have to be careful not to light the key shelf of the switchboard and yet must give sufficient light on its face to enable the operator to read the numbers with a fair degree of accuracy.

Then, too, we must be careful as to the color of the light on account of various traffic schemes in which color is used, as for instance the embracing of certain jacks in one line of a particular color to indicate the fact that all of these lines are of the same number for the use of one firm.

We are now lighting these switchboards my means of ordinary carbon filament lamps placed in reflector troughs, designed as nearly as possible for the proper distribution of the light, which we are free to say is far from satisfactory.

For some time we have been trying to get the manufacturers of the Tantalum lamp to make us a light constructed of this filament which shall be in a continuous line, in shape something similar to the Cooper Hewitt light. The difficulty in the production of the Tantalum light was caring for the excessive length of the filament necessary, but in this switchboard lighting the excessive length of filament would be an advantage rather than a disadvantage if the lamp can be constructed in such manner. We have not attempted to suggest a method of manufacture, nor to dictate the units of length in which it would be practical to produce it, though we did point out the commercial advantages for other purposes—like counter and showcase illumination.

The quantity of light we are now using for switchboard lighting amounts to about 1 candle power per lineal inch of switchboard, which is about the emission rate of the Tantalum filament. We have been assured of ultimate satisfactory results along this line by the manufacturers, but so far have not obtained anything tangible.

Another problem which is part of the power proposition in the telephone business is ventilating the exchanges, which we ordinarily do by means of small individual fan motors.

In one building, I believe, without actual count, that we have no less than 200 of these small fan motors in actual operation, or at least equipped for operation and ready for serivce.

The bills for light and power in our city exchange alone are something enormous. I am not at liberty to state the amount, but can say that it covers nearly 200,000 kilowatts per month, which certainly forces the telephone business into the power field as a real live customer.

The connection between power work and the telephone field is real, and there is also a parallelism in the problems presented in both telephone and power engineering as it pertains to the transmission of alternating currents; for the telephone engineer who understands the problems presented in his *work must also understand the problems of alternating current transmission.* It is very easy for the man who handles large generators, large engines, immense transformers, and rotary converters to belittle the telephone man because he handles a class of apparatus relatively so small. You know and I know of two classes of men; one can set up and operate a 5,000 h. p. Corliss engine and electric generator with ease, but could no more repair a millivoltmeter than he could fly. Then there is the other man who can turn down the balance staff of your watch to a nicety, yet who has no conception of how to begin to carry out the plan of erection of the large type of machinery. Both are good mechanics, but neither is qualified for the work of the other. One is a hair-spring mechanic and the other a crow-bar mechanic, and the telephone man is of the hair-spring variety.

One thing that can be said of the telephone business is that its field has grown so wonderfully that no single individual can possibly hope to master all of its phases. He must specialize, and there is no place left in it for a man to fossilize. If he will stay in it he must keep up with the progress of the art. There is no room in the telephone business for "dead ones." The tendency to specialize is also limited since we must all pull together for a common cause.

In closing I want to make a statement that can scarcely be called a prediction, as it is more of the nature of plotting a curve from observed facts. In a very few years the telephone business will be the greatest in the world. Its growth is accelerative, and its value to the subscriber increases in a geometrical ratio with the number of subscribers within reach, and on this basis I think it is fair to presume the statement just made, that nothing can prevent the telephone business from becoming the greatest industry in the world, because it contains within itself the seeds of stability; it meets a need; it meets a want, and its influence on civilization will be most far-reaching. It will bring us together under one language: it will be one of the most potent means in the fraternalization of the world, and may yet be one of the greatest factors in the universal peace plan.

I might say something about the distribution of load. Take a battery of a certain capacity. The average case of telephone load starts out about 8 o'clock a. m. and gradually goes to the maximum, which is reached at from 10 to 10:30 a. m. As the load reaches the maximum it often excels the output of the generator, consequently we start our generator at a time early enough so that the battery will become fully charged under its influence, whatever the demands made on the battery in the normal work of the exchange shall have exceeded that limit. Otherwise we would never be able to get our battery charged up to its full capacity, and then, in case of a break-down we would have full capacity to carry over a certain period.

We are trying to follow out the requirements asked of us by the suppliers of the storage battery equipment: who ask us to carry them at a certain rate under certain rules, in order to get the best effects, and to do that we have recently designed a controlling device which enables us to automatically charge this battery at a set rate. If the normal charging rate of that battery is, say X amperes per hour, we have an apparatus, in process of construction, that will enable the generator to maintain that charge of X amperes above the discharge. After having reached the full charge, the apparatus is shifted, with the result that the generator operates to carry an actual amount of current to the fuse board exactly equal to the amount of current drawn away from it. So the battery will remain fully charged as long as the generator is running. That will be done automatically. It now depends on the observation of the operator, takes considerable time, and we do not know how well it is being done.

Discussion.

Mr. F. M. Davis, JUN. M.W.S.E.: I presume that for most small exchanges, and often some of the large exchanges, the practice is to periodically charge the batteries completely, and then let them discharge to the exchange. It occurs to me that, in case of large city exchanges, the same principle might apply as is maintained by the Chicago Edison Company on their general light and power systems, viz: letting the batteries float on the line, fully charged, but with the charging machines operating continuously at such rate as to furnish the necessary current to supply the varying load, as for example a telephone exchange and thus allowing the battery to serve as a reserve, fully charged at all times, ever on the line and ready to take up sudden fluctuations or to serve as a reserve in case of a breakdown in the charging equipment. I understand that this is the practice of the Chicago Edison Company, and that they do not use the battery to furnish any appreciable power except in case of emergency.

Mr. Lambert: We follow that practice as near as we can, but in our main office, for instance, where the load may run up to 650 or 700 amperes during the busy part of the day, during the night, when the load drops down to 50 amperes, we cannot afford to run a generator of that size. But we do follow that practice up to the point when the load is one-quarter of the output of the machine. With our 400 ampere generator we follow the practice outlined, down to the point of the discharge, being one-quarter of the capacity of the machine; then we throw it over on the battery and let the battery carry it, as it will do so without detriment and without loss, and the generator is cut out for the time being.

Mr. Roper, M.W.S.E.: You speak of the necessity of lighting for the switchboard. Is any provision made so that the board can be lighted from the battery in case of trouble on the circuits of the lighting company?

Mr. Lambert: None whatever; we use gas. We are always supplied with candles, which the repairmen use in their work, but the gas usually answers all requirements temporarily.

Mr. Cravath, M.W.S.E.: Do you ever discharge a battery near its full capacity?

Mr. Lambert: We dare not do that for fear of an accident to the power, which would leave us stranded.

Mr. L. W. Carroll: Do you find it economical to run your generator at one-quarter load, or do you do that in order to keep the reserve up to full capacity?

Mr. Lambert: We run the generator when the office load exceeds one-quarter, simply using that as a standard; the people who operate the plants are instructed that whenever the office load drops down to one-quarter, that is a signal for them to shut down. It leaves them no judgment to follow in that case.

Mr. Davis: In reference to the question of choke coils, I have observed that the practice of some engineers has been to eliminate the choke coils in the charging circuit and also in the motor circuit of the ringing generator, for the reason that when the charging generators and the ringing machines are so designed as to give sufficient distribution of the commutator segments, the "ripples" (as they might be called) on the voltage of the cerrent are so fine as to be unappreciable. In any case they may be specially designed to eliminate this voltage vibration. Moreover, I understand that some telephone circuits are much less susceptible to this "commutator note" and such noise so that in some systems the choke coils are not used at all. In some cases generator current may be fed directly to the telephone switchboard without the interposition of the battery, although in any case the battery serves as a cushion, to take out any vibrations in the voltage such as would tend to produce sound in the telephone circuit, besides, of course, serving as a reservoir of power.

Mr. Carroll: Mr. Davis speaks of eliminating the choke coil from some circuits. I think this can be done. A good many circuits are operated in the way of what you might call retardation cord circuits, and give very little trouble from generator noise even without choke coils, whereas the repeating coil circuits are a little more susceptible to the changes in voltage. With the retardation coil these fluctuations do not make much difference, and you notice very little trouble from the commutator without the choking coil.

Mr. Lambert: I would like to ask a question for my own information. If we eliminate the choke coil system, and to take the place of that we take off a circuit which I will assume has retardation in it—an impedence coil—it would simply mean that this circuit could be used perhaps connected together or branched off so as not to get any pulsation force on the battery. We have no loss of power in putting in a choke coil, and if it meant that we had to put retardation coils in each branch, it seems to me it would be more economical to put this in instead of others.

Mr. Carroll: In the retardation coil circuit you refer to, the retardation coils are placed between the battery and each cord circuit. There would be a retardation coil for every circuit, but not directly in the talking circuit. Those coils have to be in there anyway, and are generally used as relays; they are wound quite high, 200 to 400 ohms. The talking current is fed through these relays and they not only act as a retarding effect to keep the battery from short-circuiting the circuit, but the two results are accomplished with the same coil.

Mr. Davis: There is one question which might be regarded as of rather minor importance, and that is the calculation of the size of the discharge leads to the exchange from the battery. In one office I know of the practice has been to allow a total drop of one-half volt from the battery to the subscriber's operator's position most remote from the battery. This maximum amount of drop is limited by its tendency to cause "cross-talk" if there is too much drop in voltage. Moreover, this calculation of the size of conductor is usually checked by not permitting a greater resistance than one-quarter ohm for the discharge leads. The reason for this is perhaps similar to the one regarding cross-talk. As for the drop in voltage, it is, of course, not allowable to let the voltage drop enough to interfere with the actuation of the relays, which would depend on the adjustment for certain voltages.

Concerning this calculation of the size of discharge leads, I should like to ask what has been the practice observed by Mr. Lambert?

Mr. Lambert: I believe I am right in saying that the telephone practice has found it is not quite so much the resistance of the leads as the retardation that produces the cross-talk. We tried an experiment at the "Canal" office, where we introduced a good deal of resistance and found no trouble from resistance. But we are adopting the practice now of using lead covered cables instead of rubber covered, in iron conduit, the latter having a tendency to increase the retardation effect. I had occasion to measure the drop in the leads in the "Harrison" office, (which I think has rather the longest leads between the battery and fuse board of any office.) I found there that under a discharge of 480 amperes we had approximately 0.25 of a volt drop.

Mr. Roper: I would ask how much voltage variation at the fuse board is permissable?

Mr. Lambert: In practice we try to never let the battery get below 22 volts. We seldom run above 27 volts at the bus bar, and occasionally have to run within closer limits. That has been brought about particularly on account of the earth currents. Between two of our offices we had considerable trouble during the day in regard to signaling. This necessitated keeping our voltage at "Harrison" office to a point about 27 volts, but since then the introduction of the "keyless" trunk system, without a return ground has given us a wider margin of operation.

When the street car systems are in full operation, then the earth currents are disseminated, and the effects are not felt quite so much. But we try to keep the voltage within reasonable limits. In the day time, when the sunlight is quite bright, we have to have our lamp signals good and bright.

Mr. J. B. Thiess: Referring to the discharge of 480 amperes at "Harrison" office, the question in my mind is, what is your normal ampere hour discharge rate per call, and how many calls per day do you figure in designing your battery for the exchange?

Mr. Lambert: Roughly speaking, we use about 1-10 of an ampere per complete connection, but that does not always include everything that goes with the load. In regard to the other question, I cannot at present give the exact information.

Mr. William Reid: In regard to the retardation coil in the charging circuit of the telephone power plant. While several people have taken up the various points of retardation, Mr. Lambert, in his discussion, has taken up the repeating coil or shunting-out system which the "Bell" company uses. Also Mr. Carroll has mentioned the retardation soil circuit. There is considerable difference in the two circuits. One seems to be used by the Bell company exclusively, or Western Electric Company, and the other by the opposition companies. The noise from the charging generator on the Bell system is much more noticeable than on the Independent, or Kellogg, Dean or Stromberg-Carlson systems of retardation. The battery of the Bell systems is fed to the subscribers instrument from the center of the repeating coil, and in the other systems the battery is fed out on the line through relays which act as retardation coils, the talking circuit of any two lines being connected on the tip side by a condenser and likewise the sleeve side. The retardation coil in the charging circuit of the ordinary telephone battery is not necessary in the Independent systems. In fact we take a standard generator with a standard number of sgments in a commutator, and it serves the purpose for charge and discharge at the same time, without any interference from generator noise, while on the Bell system it is hardly possible to do this without the generators being specially wound.

Of course we in the opposition field buy entirely (unless for special cases) the standard generator with the standard commutator. and we have no trouble whatever from cross-talk or noise due to the generator, unless the commutator gets into bad shape.

In regard to the charge and discharge of the telephone batteries, I will say that we, in the opposition field, figure a battery large enough to run the exchange, and such accessory apparatus as is necessary to run off of the battery, for a period of 24 hours on an eight-hour charge basis. By the eight-hour charge we mean we start up in the morning, charge and discharge the battery at the same time, and at the end of the day the batteries will be charged ready for the night load.

Mr. Lambert remarked that the current consumed at one call was about 1-10 of an ampere. From actual readings taken from the ammeter for every ten minutes during 24 hours, and a peg count taken of the number of calls, we find that about 0.006 ampere hour per call is a good basis upon which to figure for the telephone storage plant. The number of calls per line per day, would vary, according to the requirements of the exchange. Ordinarialy we figure anywhere from 10 to 15 calls per line per day, and the storage batteries are figured to run for a period of 24 hours. The charging generator is ordinarily figured sufficiently large to charge one set at its normal eight-hour charging rate. In other words, making it necessary to charge eight hours per day.

In regard to the drop in line, as mentioned by Mr. Davis, I will say that on a retardation coil circuit, the drop in line from the storage battery to bus bars, or to the telephone operators' positions, is about ¼ volt; it is not good practice to allow this drop to be greater than that, and of course the loss on the line would depend upon the operation of the circuit entirely. I know it is standard with a number of companies to test out the exchange line and coil so the relays of the system will operate through 1,000 ohms, and will fall back with 10,000 ohms constantly on the line. That gives a good range of operation.

In regard to the change in voltage; the lamps are so designed by a number of miniature lamp manufacturers that they will stand variance in voltage due to charge and discharge. It has been my experience in storage battery work that about the time you get the battery up to a voltage of about 27 volts, the specific gravity of the electrolyte would be about 1.210. I notice that Mr. Lambert remarked that they would start to charge when the load became ¼ the rated generator rate. In the opposition practice I am free to say we do not watch where they commence to charge with the generator, and I do not think they figure the battery quite so close as in the Bell system, because the Bell people shunt out the supervisory lamps, while in some opposition systems the lamp circuits are opened. The result is the opposition system is much more economical from the standpoint of cost of maintenance than the Bell system; consequently they do not pay so close attention to first cost, and do not have to figure the batteries so low. In fact, with a large plant the power is not very expensive.

In regard to ringing machines, where pulsating current is used; in the opposition system a ringing machine that will develop 125 watts will handle an exchange of 10,000 lines.

In regard to the retardation coil in the motor end of the ringing generator circuit, that used to be used in Independent practice, but was afterwards abandoned because the commutation became better. and a standard ringing dynamotor operated direct from the battery is standard practice among the telephone companies at the present time.

Mr. Carroll: I would ask what the practice is in furnishing generators according to the size of the plant. It seems to me, in order to get an economical output in the generator, in starting the generator the battery load and the load on exchange will be about the full load; so, when the exchange load increases, it will decrease the amount in the battery, and I think a great deal of economy can be had by forcing the generator in that way.

Mr. Lambert: That is exactly the practice we try to maintain. With reference to the extraordinary size of plants used by some companies one thing must be taken into account, and that is, excessive rent in the down town district, which it is not necessary to pay in the outlying territory. In the latter case a different practice is followed. It would be of great advantage in such offices as our "Harrison" office to add extra floor space.

Mr. Reid: I can easily see how the question of rent or floor space might cut considerable figure. Undoubtedly it would be just as economical to take the current direct from the generator, possibly even more so, especially if you could use the current direct from the generator and allow only the surplus that the generator is putting forth to charge the battery. In a small exchange, after the six o'clock peak, a small battery down town would carry load until such time as the force was around in the morning, and in that way I can easily see why they would adopt such practice. I should think it would be a good thing where rent is high. Of course, in the ordinary small town exchange, rent is of secondary consideration. You stated that you had several forms of power to take from, but in the ordinary small exchange of 2,000 subscribers it would hardly be policy to take a chance with a local electric lighting company. If you had a battery of sufficient capacity to carry the load for a period of 24 to 48 hours, an exchange would be comparatively safe as I have noticed that generally within 24 hours a man can always do something.

Mr. Lambert: In our main office, through some accident which we could not control, we ran that plant for about three months, when I think if our power plant had been shut off for twenty minutes we would have been stranded.

Mr. Reid: I think under those circumstances if you would reduce your battery to such size as you mention, if the source of primary power did go back on you (if for only 20 minutes during five years) you would find that a reserve source battery to carry the plant for say 24 hours, would more than pay interest on the money invested in the plant.

Mr. Roper: I think that today the supply of power has considerable influence on the size of the battery. In the down town district the telephone exchanges are supplied with two or more independent sources of current; (that is, independent sets of mains or feeders) so that trouble in one lighting main will not entirely disable the telephone exchange. In addition, the lighting company carries considerable reserve of its own to maintain its own service free from interruption.

Mr. Davis: This meeting has dealt with a subject in which I have been greatly interested for several years. Though it seems to have received very little attention from engineers in general, I have taken much interest in some of its many-sided problems.

The interesting character of telephone power is found in the wide and inclusive nature of the problems confronted by the engineer in a field where one would casually expect to find little of interest outside of very narrow limits.

We sometimes hear the learned discussion of general power engineers concerning questions of high voltages, resonance effects, line surges and multikilowatt capacities, and marvel at the splendid achievements of these men of genius. Has it not been well demonstrated in the valued paper and ensuing discussion here tonight, that in telephony we have the essential elements of many of the great problems generally ascribed solely to the "larger field?"

General telephone power practice involves in one system or another a great variety of power apparatus among the more common of which are batteries, dynamo-electrical machinery, power switchboards and prime movers, such as gas and steam engines.

In the design and operation of certain types of harmonic ringing generators, problems concerning capacity and wave form had to be solved.

The absolute necessity for due regard for balance in general telephone circuit design will be recognized at once by all telephone engineers.

Although many of the absolute values concerned are relatively small, still these various problems exist and must none the less be solved adequately in each case, in order to insure a telephone system at once practical and efficient.

METHODS OF ELECTRIC LIGHTING FOR RAILWAY TRAINS.

DUGALD C. JACKSON, M.W.S.E.

Presented May 15, 1907.

This paper contains a summary of the results and a portion of the data obtained in a series of tests and examinations of the different apparatus used in the electric lighting of western railway trains, which were made under my direction during the past two years, while still connected with the University of Wisconsin.

The greater part of the work was carried out by undergraduate students in the engineering courses of that University, directed by Mr. Edward Wray who was a graduate student for one of the years; a portion of the work was carried out with the assistance of Mr. F. W. Huels, who supervised some tests of train lighting apparatus in connection with his investigation of the vibration of railway trains caused by the ordinary baggage car installation of electric light engines. This paper consists mostly of a summary of Mr. Wray's very extended report on the work.

A number of railway people gave their advice and assistance in this work, and I must particularly refer to the courtesies of Mr. J. F. DeVoy, Mech. Engr. of the Chicago, Milwaukee & St. Paul Ry.; Mr. M. C. B. Young, Mech. Engr. of the Chicago, Burlington & Quincy Ry.; Mr. W. J. Bohan, of the Northern Pacific Ry., and Mr. A. J. Farrelly, Elec. Engr. of the Chicago & Northwestern Ry.

The results of the examination and tests divide themselves naturally into three divisions:

1. Those connected with those lighting systems in which a steam driven generator set is located in the baggage car.
2. Those systems in which a generator of the electric current is located under each of the cars, or one or more of the cars, and driven by a connection from a car axle.
3. The arrangement in which a storage battery is located on each car, and no provision is made for charging it during the run of the train.

It is usual to use a storage battery or batteries at some point or points on the train with the first of these methods, and it is necessary to use a battery for each car equipped with a generator in the second of the methods.

BAGGAGE CAR GENERATING PLANT.

Various railroads have used the so-called baggage-car or head-end system for many years. The equipment generally consists of a generator of from 20 to 25 kw. capacity driven by some suitable engine. The 3-cylinder Brotherhood engine was formerly used on the Pennsylvania R. R. A number of roads leading westward and northwestward from Chicago have used Westinghouse standard engines, following the lead of the Chicago, Milwaukee & St. Paul Ry.; and of recent years a number of the roads have introduced turbine generator sets to replace the sets including reciprocating engines which therefore had been used.

As pointed out by Mr. F. W. Huels in his recent paper, the reciprocating engine sets cause, not only very appreciable, but annoying vibrations in the trains when the trains are at a standstill; and this is true even when care is taken to place the reciprocating engine outfit in the location and position which will be least favorable to the setting up and transmission of vibrations through the train. These vibrations are entirely absent when a proper turbine generator set is used. The railroads seem to have taken as a standard the turbine generator set made by the General Electric Co., including a 25 kw. generator driven by a Curtis steam turbine.

The laboratory of the University of Wisconsin possesses a turbine outfit of this character on which careful tests of steam consumption were made. The results of these tests are laid down in Fig. 1. It is notable that the steam consumption of this turbine is substantially the same at different loads regardless of variations of steam pressure from 63 to 94 lb. per sq. in.

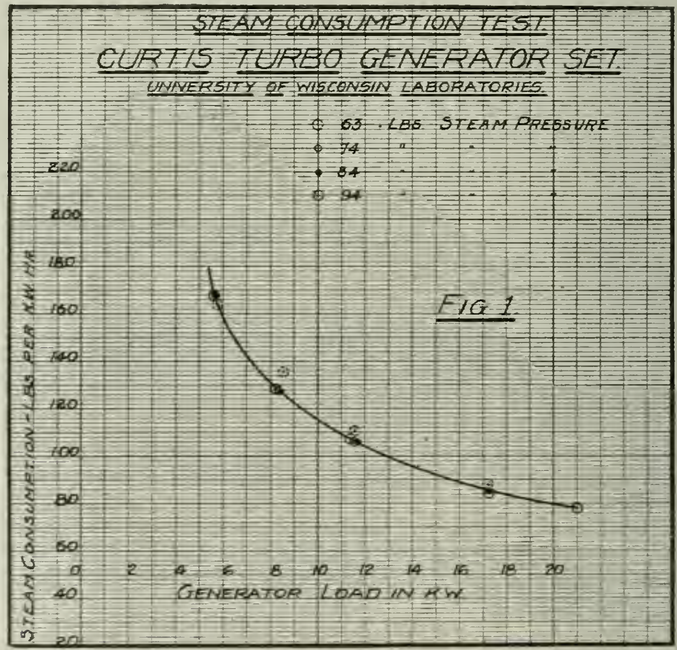


FIG 1.

The steam consumption is not as satisfactory as might be hoped, but after this test was made, some change of the nozzles on the turbine was made by the General Electric Co., and the steam consumption was improved about 8 per cent. at full load, and I understand that a similar change has since been made in the nozzles on the turbines of the Chicago, Burlington and Quincy Ry. equipment which we had tested.

In Fig. 2 are shown the results of the road tests, indicating the load on the turbine of train No. 1 in the run between Chicago and Denver, of the Chicago, Burlington & Quincy Ry. The turbine in this instance is installed in the front end of the baggage car, and two sets of storage cells are placed on the train, one located under the baggage car and the other under a Pullman car at the rear of the train. The turbine receives its steam from the locomotive through a pipe located beneath the cars, joined by flexible hose connections between cars; a reducing valve is located at the locomotive for the purpose of reducing the steam pressure to 80 lbs. per sq. in. The capacity of the turbine is 25 kw. and its speed is 3,600 rev. per min. The exhaust steam passes into the atmosphere through a steam funnel above the car.

The outfit is accompanied by a switchboard containing electrical measuring instruments, switches, steam gauge, etc. Amongst the switches is an automatic overload and reverse current circuit breaker to protect the turbine against overload, and also to protect the batteries against short circuiting in case the turbine stops operating. There are 54 cells in each battery and each cell has 240 ampere hours capacity. The batteries float on the line. The train line is of the usual character with a loop to the rear of the train.

On the test run with this turbine a standardized steam gauge and a separating calorimeter were attached to the steam pipe close to the turbine steam chest. Standardized electrical instruments were also used in the electrical circuit, and observations were made every fifteen minutes during the operation of the electric light set.

Referring to the curves on Fig. 2 which show the data of the test, it will be observed that the generator load is never greater than 17 kw., and the average load is less than 11 kw., while the generator is of 25 kw. capacity.

There are, however, several good reasons for installing a 25 kw. outfit. One of these is due to the fact that it is necessary to have the baggage car generating outfit of capacity large enough to take care of extraordinarily long trains, which the railroad may be called upon to make up in cases of unusually heavy traffic. It is also to be noticed that the steam pressure may fall rather low, in which instance a turbine of smaller capacity might be unable to deliver sufficient mechanical power to drive its dynamo even at the load of 17 kw.

The steam consumption which is set down in Fig. 2, is taken from the tests of the University of Wisconsin turbine (which is a duplicate of the "Burlington" turbines), and the steam consumptions are plotted to correspond with the various electrical outputs. The steam consumption is somewhat higher than that of the reciprocating engines used under similar conditions, but the other advantages of the turbines, including that of the freedom from vibration effects, are doubtless sufficient to counterbalance this.

For the total run between Chicago and Denver the steam consumption is approximately 19,400 pounds, and this is approximately 3 per cent, of the total water supply to the locomotive boiler as indicated from a count of the locomotive tank fillings.

In Fig. 3 are shown the results of steam consumption tests made on a Westinghouse engine used on the "North Coast Limited" train of the Northern Pacific Ry., and Fig. 4 gives the results of the road test of this outfit. The equipment includes a Westinghouse standard engine with a direct connected 25 kw. generator installed in the forward end of the baggage car, the engine being arranged to receive steam from the locomotive through a pipe line and flexible hose connections, there being a reducing valve at the locomotive which is intended to deliver the steam to the pipe connected with the electric light engine at 80 pounds pressure.

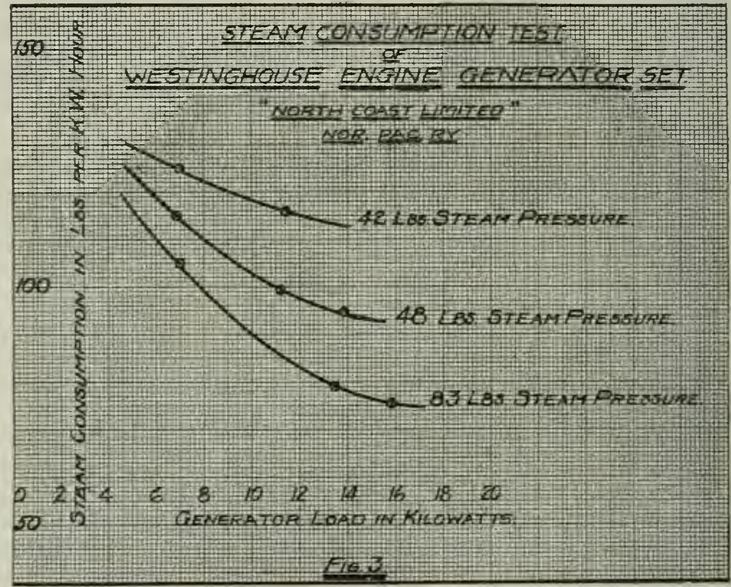
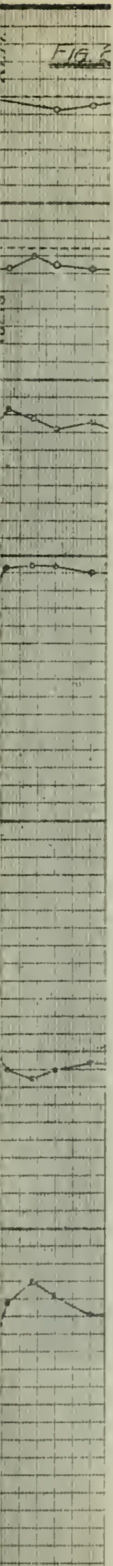
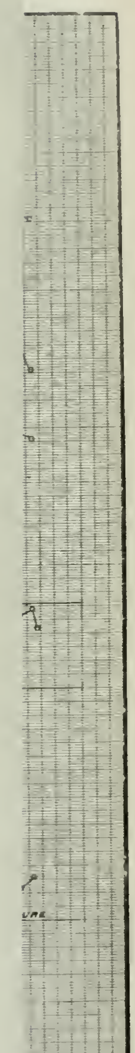


Fig. 3.

An auxiliary storage battery is provided on each passenger car. These batteries are kept separated from the regular train lighting line, but are arranged to be used with one circuit of lights in each car when needed, and to be charged during the night by being connected to the train line at that time. The charging of the batteries is carried on at night when most of the lights throughout the train are turned off, otherwise serious injury to the lamps would occur by

volts.
when

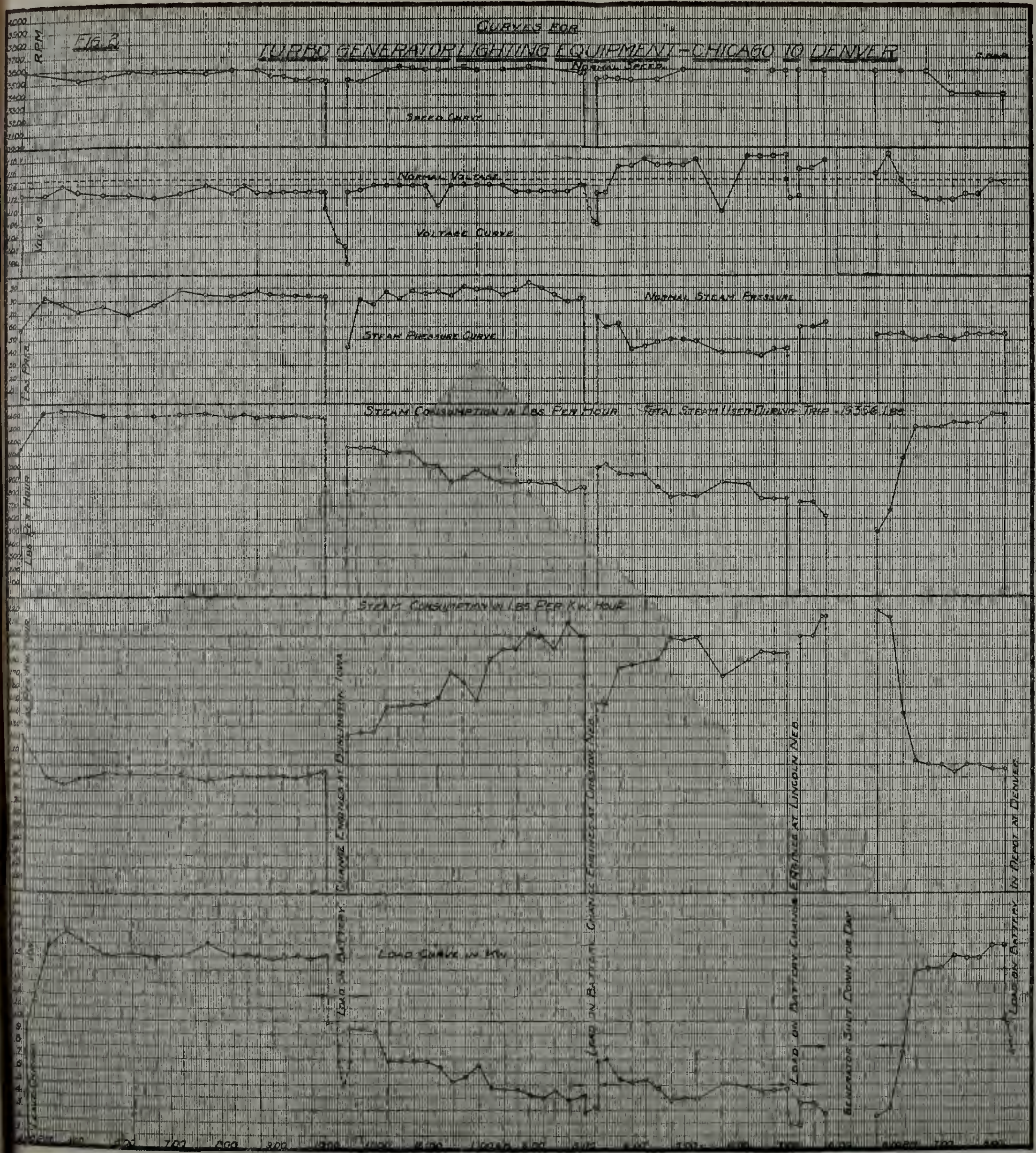




manner
After

Fig. 2

Curves for Turbo Generator Lighting Equipment – Chicago to Denver



raising the generator voltage to the charging pressure of 115 volts. The batteries are also charged very thoroughly once a week when in the storage yard.

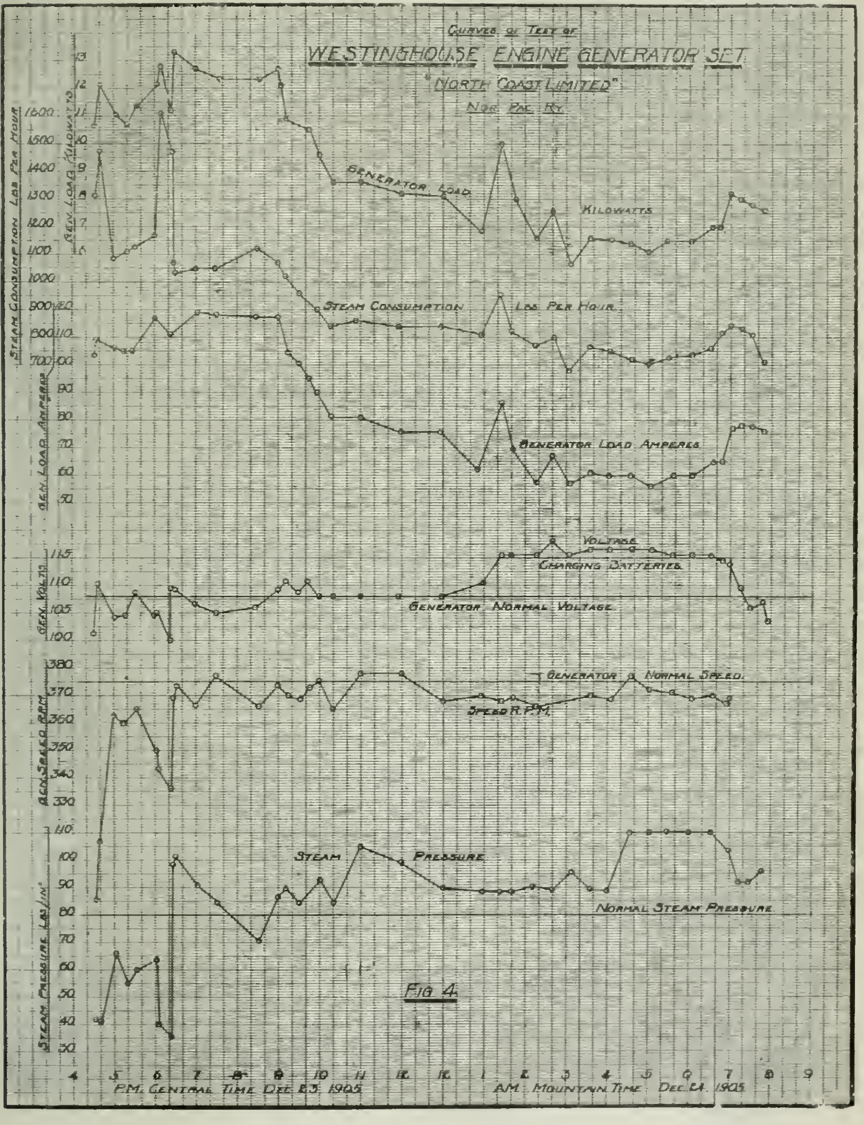


FIG 4.

The records of tests on the road were kept in a similar manner to those taken on the Chicago, Burlington and Quincy Ry. After the test had been made on the road, the steam consumption of the engine was tested in the yard at St. Paul and the results are set forth in Fig. 3. The road test was made on two separate equipments on two separate trains, but the steam consumption test in the yard was made only on one train on account of insufficient time. Fig. 4 gives the data for one night's run with one equipment, this being a typical record.

In Figs. 1 and 3 is shown a notable difference between the steam turbine and the reciprocating engine with shaft governor, in respect to the variation of steam consumption with steam pressure. The governor of the reciprocating engine is arranged to vary the admission of steam to the engine cylinder for different fractions of the stroke, so as to maintain the constant speed, and in case of falling pressure the expansion of the steam becomes uneconomically small. In the case of the turbine, the governor acts in a different manner, and the steam used is expanded more nearly uniformly at all steam pressures.

This throws some light upon the effect of the efforts of locomotive engine men to relieve the drain of steam from the locomotive boiler by partially closing down the valve in the steam pipe to the electric light engine. It is the engine man's supposition that in doing so he reduces the amount of steam going to the electric light engine, but, in fact, he only increases the amount of steam going to a reciprocating engine providing sufficient steam gets through to actually keep the engine running at the normal speed. If the locomotive engine man would alter the reducing valve so as to increase the pressure at the electric light engine, instead of trying to throttle the flow of steam thereto, he would reduce the steam consumption; but the efforts which he does ordinarily make,

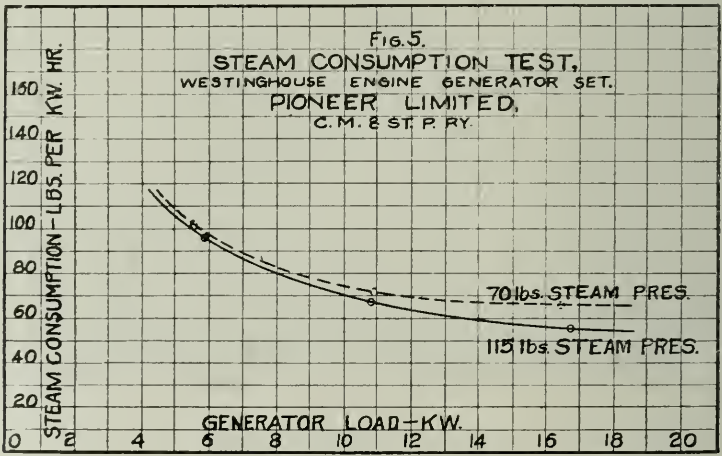
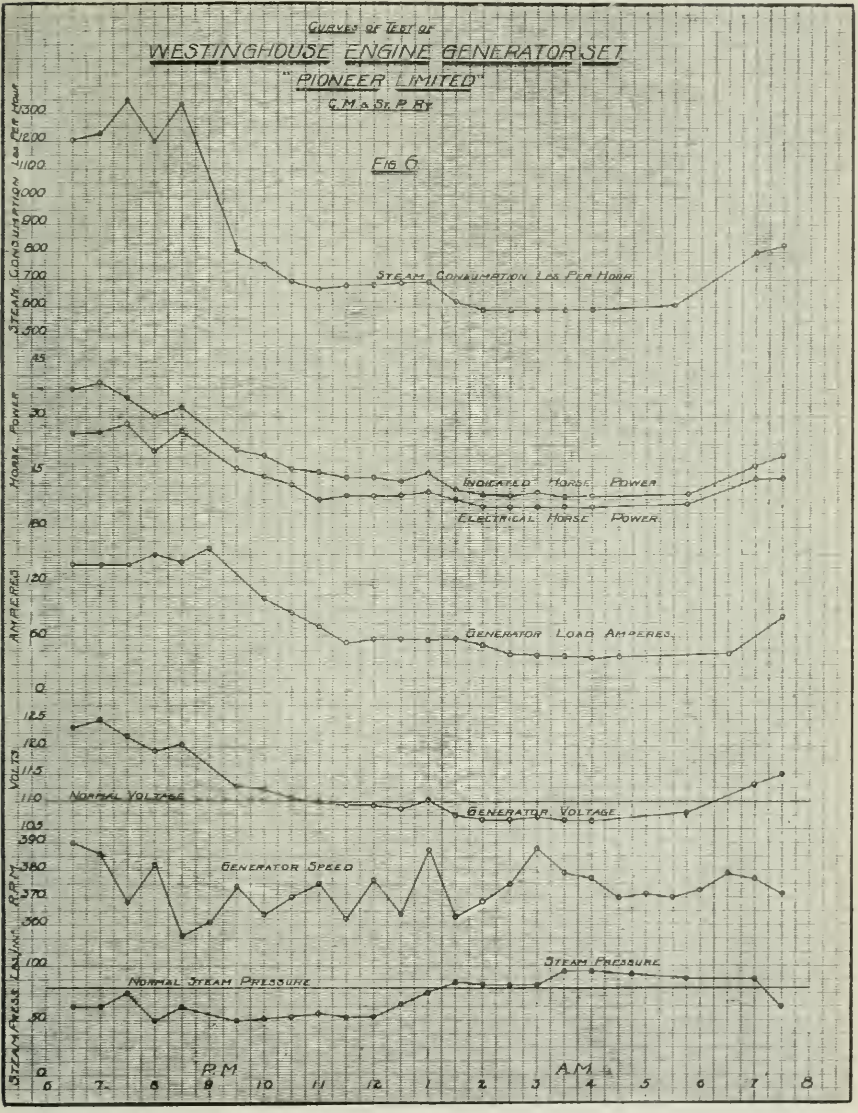


Fig. 5.
STEAM CONSUMPTION TEST,
WESTINGHOUSE ENGINE GENERATOR SET.
PIONEER LIMITED,
C. M. & ST. P. RY.

are misguided and increase the steam consumption, as already said.

The curves showing steam consumption on the road are plotted



from kilowatt-steam curves derived from the steam consumption test made in the yard.

In Figs. 5 and 6 are shown corresponding results taken from an outfit on the "Pioneer Limited" train on the Chicago, Milwaukee & St. Paul Ry. On this train the baggage man looks after the apparatus in the baggage car and the brakemen look after the electric connections between cars, etc.; while the "Northern Pacific" and "Burlington" roads provide an electrician for each train. Similar methods were used in the tests on this road compared to those on the other roads. The engine was probably in better order than the engine on the Northern Pacific Ry. and was, therefore, somewhat more economical. Two round trips between Chicago and St. Paul were made. On the first trip north, the average steam pressure was 92 lbs; the average load on the dynamo was 8.7 kw., and the average steam consumption was 690 lb. per hr. On the return trip, the average steam pressure was 108 lb; the average load of lamps was 8.9 kw.; and the average steam consumption was 580 lb. per hr. On the second trip, making the trip northward, the average steam pressure was 75.7 pounds; the average load of lamps was 9.8 kw.; and the average steam consumption was 780 lb. per hr. On the return trip the average steam pressure was 90 lb.; the average load of lamps was 9.5 kw.; and the average steam consumption, 770 lb. per hr. The steam consumption on these runs is less than on the Northern Pacific Ry., partially due to the good condition of the engine, and partially due to the higher steam pressure. A storage battery is maintained on the train for auxiliary lighting while the engine is disconnected for engine changes.

A similar equipment of 17 kw. capacity was tested on the Chicago & Northwestern Ry. In this instance the time of the test occupied 5.75 hours. The average load was 8.2 kw., the average steam pressure 86 lbs.. and the average steam consumed was 870 lb. per hr. The total steam consumed during the test was approximately 5,000 pounds.

This equipment differed from those of the Chicago, Milwaukee & St. Paul Ry., the Chicago, Burlington & Quincy Ry., and the Northern Pacific Ry. in using an auxiliary of Pintsch gas lighting instead of using storage batteries.

The records of the tests and the continuous records of the railways show that these baggage car sets have given good satisfaction They use a considerable amount of steam but they are reasonably reliable, and (especially when a turbine generator set is used) are without qualities which interfere with the comfort of the passengers. They give admirable means for electric lighting trains which are made up complete at one end of a run, and are continued through to the termination of a long run without being broken up. They cause serious inconveniences in connection with any trains which have to be broken up, as, for instance, by setting cars on a side track or where cars must be picked up at junction points, etc., since difficulty is likely to occur with the batteries even if these are distributed uniformly among the cars. With the arrangement of one or two batteries on the train, instead of using a battery on each car, a car is obviously left without light in case it is taken out of the train, unless it is also supplied with Pintsch gas fixtures or oil lamps.

The advantages of doing away entirely with flame lights on the cars is too manifest to require more than mention, after the moral pointed in certain recent accidents.

AXLE DRIVEN PLANT.

Careful tests were made on several of the axle driven equipments manufactured by different companies. These tests were made more particularly on the "Northern Pacific" and "Burlington" railroads, but some attention was given to similar sets which have been installed on certain other railroads.

An axle driven outfit consists as a rule of a small generator, of approximately 3 kw. capacity, mounted on the truck of a car and driven by a belt or gears from an axle. As this generator partakes of the variations of the speed of the train, it is necessary to use some special regulating means in order that the electrical pressure at the lamps may be maintained uniform without regard to the speed of the generator. In certain instances unique methods of much ingenuity, though of considerable complexity, have been adopted for this purpose.

The regulator control may be classified in four types:

1. One of these is very simple in conception, and depends upon mounting the generator in such a manner that the belt may slip at the higher speeds, so that the generator may be expected to run at a reasonably constant speed irrespective of the variations of the train speed above a certain predetermined limit, and the generator is automatically cut out of circuit at lower speeds. This arrangement has been used in Europe in connection with the Stone equipment developed in England. The extra slip of the belt which occurs as the speed of the train increases, is brought about through the additional load which comes on the generator on account of the extra charging current that flows into the accompanying storage battery as the generator pressure rises. The tendency is towards maintaining a constant generator current which must be absorbed by the battery when the lights are turned off.

2. Another of the arrangements for generator control consists in utilizing the effects of armature reactions, which are magnified by the design of the dynamo, so as to keep the current of a uniform value irrespective of the speed of the armature above a certain predetermined mark. This plan is now used to some degree, as I understand, in Germany. It was also early tried in this country, but did not succeed in effecting a permanent lodgement in practice. It also operates in the direction of producing a constant generator current.

3. It is possible, and has been tried, to place a differential winding on the generator field windings which decreases the excitation

as the generator pressure and, consequently, the battery current increases, and thus tends to regulate the generator pressure.

4. The most successful of the arrangements of generator control comprise means for varying the current flowing in the shunt field winding of the generator so as to compensate for changes in speed. All of the successfully used axle driven outfits which are on the American market to-day utilize this manner of operation, but there is a wide diversity of methods and mechanisms for applying the process.

In most of the axle driven equipments the control is executed with the object of maintaining the generator current constant, upon the hypothesis that the batteries will absorb or produce the excess or deficit of current compared with that utilized in the lamps which chance to burn at any particular moment. The idea leads to simplicity in the controlling apparatus, but it also leads to variations of pressure on the lamps which at times are quite unsatisfactory. Constant pressure control is, of course, the ideal sort of control to be used where incandescent electric lighting is involved, but no successfully operated American apparatus has yet been developed to follow this method. In most instances a special variable rheostat is connected in the lamp circuit to reduce the range of variation of pressure at the lamps, and this rheostat is controlled by the same mechanism that controls the generator field current. Various means are used to operate the generator field rheostat and the lamp rheostat. For instance, an auxiliary motor and suitable relay magnets are used in the Consolidated and the McElroy axle equipments. In the Newbold and certain other equipments the rheostats are controlled by a solenoid with its winding placed in the generator circuit. In the Bliss equipment an ingenious plan is utilized to introduce a suitably variable counter electro-motive force in the generator field circuit by means of the armature of a small auxiliary machine called a bucker.

Of the various equipments now on the market most of them control by the constant generator current method. The Bliss equipment is arranged for maintaining the battery current independent of the lamp load instead of the generator current being maintained constant; while the McElroy equipment operates directly as a matter of voltage control.

It is to be noted in this connection that a strictly constant generator pressure would be impracticable even if it could be maintained, because the battery now obtainable requires the impressed voltage to be increased for the purpose of charging it, and means must be provided whereby the generator will automatically increase its pressure when the battery is to be charged, while the lamps are at the same time properly protected by means of a rheostat from an excessive pressure.

Each of the axle driven systems consists essentially of a generator provided with a suitable pole-changer to maintain the appropriate polarity of the electric circuit whichever direction the car may run, and suitable means for transmitting mechanical power from the car axle to the generator shaft; an automatic cut-off switch, which is actuated by the generator pressure or the train speed, so as to disconnect the generator from the car circuits when the speed falls below a predetermined point, usually 18 or 20 miles per hour, and also reconnect the generator to the circuits when the train speed rises above that limit; a regulator for the purpose of maintaining a suitable voltage irrespective of the speed of the train; a storage battery; and the needful wiring, switches, and lamps within the car. In most instances the generator is driven by means of a belt from a pulley mounted on one axle of a car truck, and the generator itself is generally mounted on a framework supported by the truck frame. The generator pulley is ordinarily arranged with a flange at each end and its face is perforated for the purpose of minimizing the effects of sand, cinders and the like. The generator is sometimes built with a portion of hard steel in the pole pieces for the purpose of maintaining the polarity of the magnets and preventing the possibility of a reversal of the electric polarity.

Tests were made of the Consolidated axle equipment on the Northern Pacific Ry. In this equipment the generator is a bipolar shunt wound dynamo. It is provided with self-oiling bearings, and is incased in a dust-proof, wrought iron casing, which is provided with suitable covers and hand holes for repairs and inspection. This is mounted on an iron frame bolted to the outer face of the forward truck sill, and pivoted on a rocker arrangement with a heavy adjustable spring to maintain the proper belt tension. The pole-changer includes a worm fitted on the armature shaft connected with a worm wheel on which is mounted a cam of peculiar construction and provided with a cam follower which runs continuously in a certain cam slot as long as the train operates in one direction, but which is crowded into a different cam slot if the train is operated in the opposite direction. When this transfer of the follower from one slot to the other occurs, a reversing switch is moved which maintains the dynamo in proper polarity with the external circuit. A pole-changer is manifestly necessary on account of the storage batteries.

The battery on the Northern Pacific car consists of 16 cells of the type, E 13, made by the Electric Storage Battery Co., and located under the car, each cell being of 240 ampere-hours capacity. The battery is connected in parallel with the generator and line.

The regulator is a very important and somewhat complex part of this equipment. It is arranged to control the generator by means of a rheostat so as to maintain the generator current substantially constant, and also to maintain the voltage at the lamps fairly uniform by means of a lamp rheostat as the battery changes in pressure, thus making the voltage of the lamps reasonably independent of the number of lamps in use or the condition of the battery. The rheostats are operated by means of ratchets driven by pawls moved by means of a small electric motor, and the pawls are controlled respectively by an electro-magnet in the main generator and lamp circuits for the generator control and an electro-magnet across the lamp line for the voltage control of the lamps. The arrangement of the generator control makes it possible for the regulator to maintain a somewhat larger generator current when the lights are turned on than is maintained when the lights are off. This regulator seems to afford reasonably good satisfaction.

The automatic switch in this device is arranged to connect the generator with the lamp and battery circuit when the generator voltage rises slightly above battery voltage, and to disconnect the circuit when the generator voltage falls below the battery voltage. an ingenious plan being utilized to improve the positiveness of the action of the switch.

The problem of testing such an apparatus in actual operation on a railway train is a peculiarly difficult one. Everything in the system is constantly in fluctuation. The speed of the train is an extremely variable factor, and there are considerable fluctuations of current and generator pressure with these fluctuations of speed. In addition to this the generator alternately disconnects and reconnects with the line when the train comes to a stop and starts again; while the lights are fed at one time from the generator in conjunction with the battery and at another time from the battery alone. In making these tests it was desired to get observations which would make it possible to draw curves showing the relations that exist between the train speed, the generator voltage, the lamp voltage, the battery voltage, the generator current, the lamp current the battery current and the field current, on the one hand; and on the other hand, the integrated energy data relating to the total generator output, the total energy consumed by the lamps, the total battery charge and the total battery discharge; it was desired to have these cover the duration of an entire trip between St. Paul, Minn., and Portland, Ore., and return.

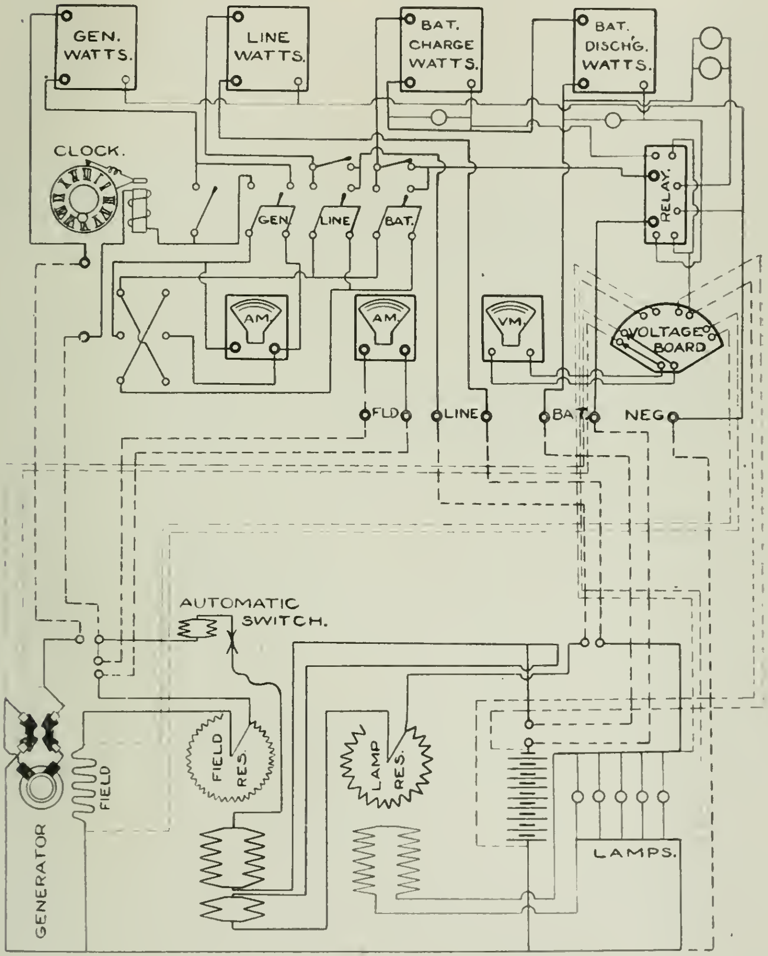
For the purpose of facilitating the taking of all the required data, a switchboard was constructed for the purpose of bringing the required electrical instruments into close association with each other so that all the required readings could be taken within a few seconds of time, and also so that all the instruments and switches required in the testing could be placed in one seat of the car at the end in which the regulator is located in its closet.

In making all the tests on the axle driven sets the main circuit connections between the switchboard carrying the testing instruments and the regulating devices, consisted of heavy insulated copper cables with a cross section corresponding to No. 4 B. & S.

gauge wire, so that the losses in these connections were negligible, as they were short as well as of ample cross section.

In Fig. 7 is indicated the arrangement of the instruments in

FIG. 7.
TEST CONNECTIONS,
CONSOLIDATED AXLE EQUIPMENT.



connection with the apparatus in the test of the Consolidated equipment. The lower half of the diagram indicates the wiring connections of the generating equipment and lamps, and the upper half of the diagram reresents the arrangement of the testing instruments, the various leads between the equipment and the instruments being shown by dotted lines.

For the purpose of assuring a satisfactory separation of the integrating wattmeter record showing the energy put into the battery during charging, from that showing the energy taken out of the battery during discharging, a special polarized relay was constructed to operate in connection with two integrating wattmeters, one of the wattmeters being utilized to record battery charge and the other to record battery discharge. This polarized relay consisted essentially of a heavy yoke of soft iron wound with about forty turns of No. 4 B. & S. insulated copper wire, through which the total battery current passed, so that the iron core was magnetized in one direction during the charge of the battery and in the reverse direction during the discharge. Suspended between the pole pieces of this yoke was one end of a strong electro-magnet of fixed polarity. This consisted of a strip of soft iron wound with 400 turns of No. 20 insulated copper wire which were placed directly across the terminals of the battery, with lamp resistance to prevent the current from being excessive.

Mounted on either side of this suspended magnet was an insulated brass button. With the battery current flowing in one direction. as upon charging the battery, the reaction between the magnetism of the yoke and that of the suspended magnet drew the latter over until the brass button came in contact with two contact points and thereby completed the circuit through the voltage coil of the wattmeter intended to register battery charge. At the reversal of the battery current, the polarity of the yoke was reversed and the suspended magnet was therefore drawn over toward the other pole of the yoke, whereupon a brass button came in contact with two contact points on this side of the suspended magnet and completed the circuit through the voltage coil of the wattmeter intended to register battery discharge, causing it to record, while the other wattmeter was then inoperative on account of its voltage coil being open.

The current coils of both wattmeters were placed in series with the battery circuit so that all battery current passed through them.

By means of two pilot lights, indication was afforded as to which wattmeter was operating at any time, which served as a check upon the operation of the polarized relay.

It was also desired to determine the total time of generator operation. An ordinary alarm clock was utilized for this purpose, but it was provided with an electro-magnet attachment by means of which the clock stopped when current flowed through the generator circuit, and the clock mechanism was released when the generator was cut out of circuit. The clock, therefore, kept a record of the duration of time when the generator was out of circuit during the run.

After the road tests had been made, a test of the efficiency of the generator was made, for the purpose of arriving approximately at the amount of power required to drive it during a run. This was done by removing the belt from the generator and driving it at various speeds without load, by means of a small rated motor, the generator being excited with various exciting currents. The losses in the electrical windings of the machine could be readily computed from the electrical resistances of the parts; and with the results of the rated motor tests and these computations, the efficiency of the apparatus can be arrived at with a sufficient degree of approximation.

It is not my desire to present the great masses of data taken on this and similar tests of axle driven sets, but I will give a certain amount of typical data to illustrate the operation of the equip-

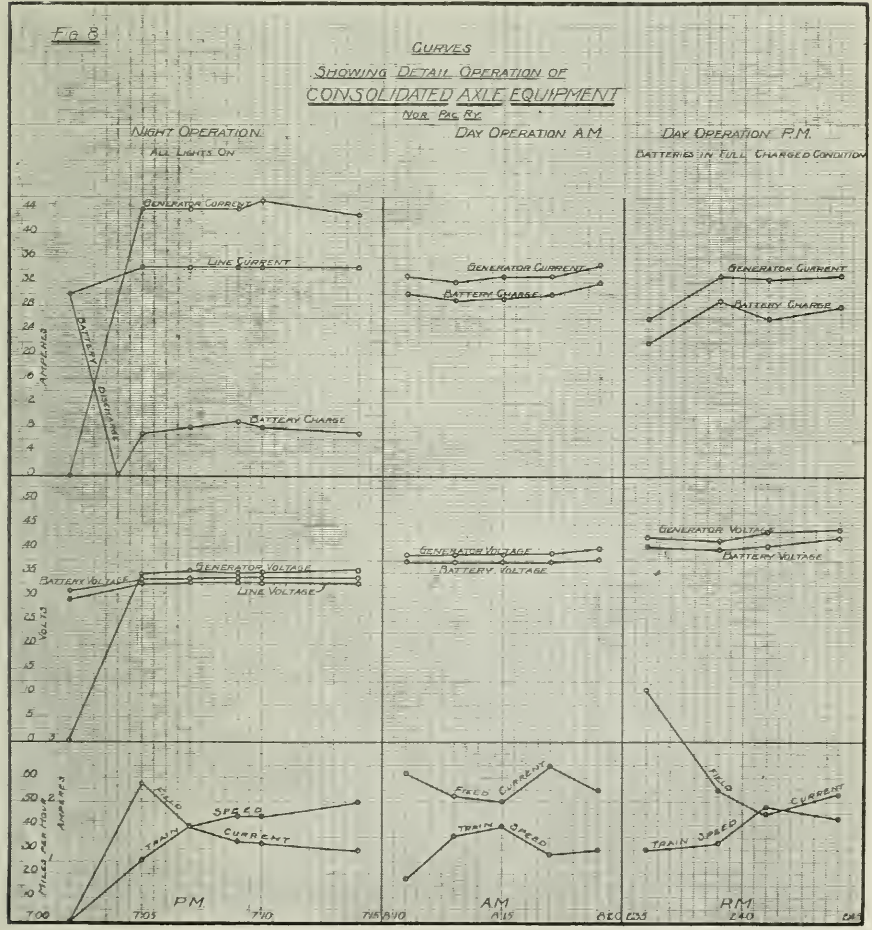


Fig 8

Curves Showing Detail Operation of Consolidated Axle Equipment Nor. Pac. Ry.

ment. The Consolidated equipment on the Northern Pacific Ry. was new and the pole-changing device failed to operate suitably, so that only a part of the run one way was effective for testing. The duration of the test extended over 31 hours, during which the train was above the cutting-in speed and the generator was operating for 23½ hours, and the lamps were lighted for 13½ hours. The total generator output during this period was 28.6 kw. hr., the lamp consumption was 14.6 kw. hr., the battery charge was 12.2 kw. hr., and the battery discharge was 4.7 kw. hr. The average generator efficiency was 80 per cent., and assuming 3 per cent. loss in the belt, the average power absorbed from the axle is 2.1 HP. The total efficiency for the run computed by taking the ratio of the

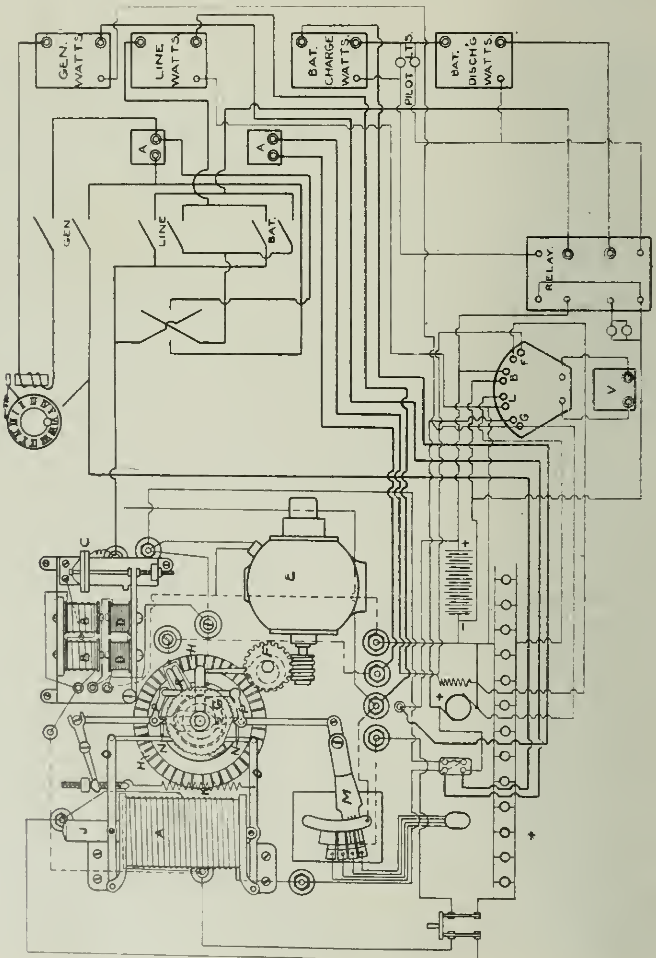


Fig. 9.
TEST CONNECTIONS,
CONSOLIDATED AXLE EQUIPMENT.

lamp consumption in kw. hr. to the mechanical power put into the generator, is slightly under 40 per cent.

In Fig. 8 are given some of the results of the operation which are typical of the results obtained throughout the est of this equipment The generator current is notably uniform but the line voltage varies considerably, which is to the disadvantage of the lamps and to the discomfort of the passengers. The voltage variation was from 29 to 33 volts during the part of the run from which the data of this curve were selected, and this is typical of the operation of the equipment. When the lights were turned on, the generator current was substantially uniform at about 44 amperes, independent of the speed of the train, and furnished some charging current to the battery even with all lights on; while the charging current into the batteries was about 33 amperes when the lights were off. It is a fact that the regulator of this equipment ought to be set for a somewhat lower current to prevent the serious overcharging of the batteries which is likely to soon exhaust their capacity by boiling out the active material.

A test with a similar equipment except with a different arrangement of the regulator was made on the "Burlington" railway, and Fig. 9 shows the arrangements for carrying out this test. The car carrying the equipment is a Pullman sleeping and observation car, and the generator is identical with that tested on the Northern Pacific Ry. The run was between Chicago and Kansas City. On the outbound trip from Chicago, the duration of the test was 14 hr., 10 min., with the generator operating during 11 hr. and 35 min. of this time. The generator was not operating during 2 hr., 35 min. of the time, of which 1 hr., 22 min. was occupied by stops, and during 1 hr., 13 min. the train was running below the speed at which the automatic switch cuts the generator off from the car circuits.

The battery furnished the total current for the lights for 2 hr., 35 min. The total generator output was 19.6 kw. hr., the lamp consumption 8.38 kw. hr., the battery charge 7.9 kw. hr. and the battery discharge 1.86 kw. hr.

On the return trip from Kansas City to Chicago the total duration of the run was 13 hr., 14 min., with the generator operating 10 hr., 55 min., and not operating 2 hr., 47 min. Of the latter time 1 hr., 24 min. was occupied in stops, and for 1 hr., 23 min. the train was running under speed with the generator cut off from the car circuits. The lights were on the battery 2 hr., 47 min. The total generator output was 19.2 kw. hr., the lamp consumption was 7.28 kw. hr., the battery charge 7.3 kw. hr. and the battery discharge 1.87 kw. hr. Computing the efficiency of the equipment for the round trip gives an average of about 31 per cent.

In Fig. 10 is shown a record of typical results obtained on this run. In this, also, the regulator was set so as to charge the battery at too high a rate, and the batteries were tremendously overcharged on the trip. There is reason in a certain amount of battery overcharging in these axle driven equipments, for the purpose of standing on the safe side by always keeping sufficient charge in the battery to meet the demands of the lights in case of emergency; but the overcharging is being overdone. The low efficiency of the equipment is largely due to the losses caused by this overcharging of the batteries.

In Fig. 10 are shown the results of the operation of this equipment under four different conditions: namely, all lights on, half the lights

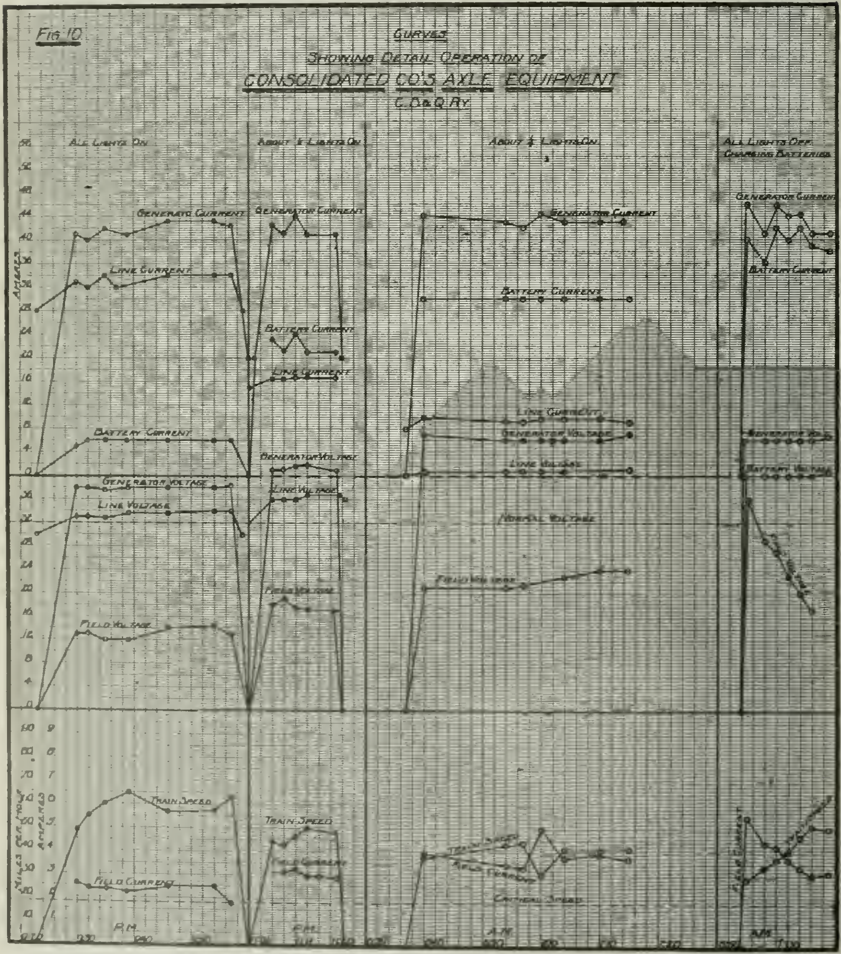


Fig 10

on, one-quarter of the lights on, and no lights on but the generator charging the battery. The curves show that the generator current remains substantially constant at all speeds of the train while the generator is connected with the circuit, but the lamp voltage varies considerably.

In Fig. 11 are exhibited the typical results of the tests of a Newbold axle equipment taken on the Northern Pacific Ry. in the run between St. Paul and Portland. In this instance the generator is a 4-pole dynamo with a capacity of 40 amperes at 60 volts for full load. It is suspended from the outside of the front end of the truck sill, pivoted on a rocker roller which is set on the supporting frame and provided with an adjustable spring to maintain the proper belt tension. The belt is a 4-ply canvas and rubber belt, 4 in. wide. The oil chambers of the generator bearings are large enough to

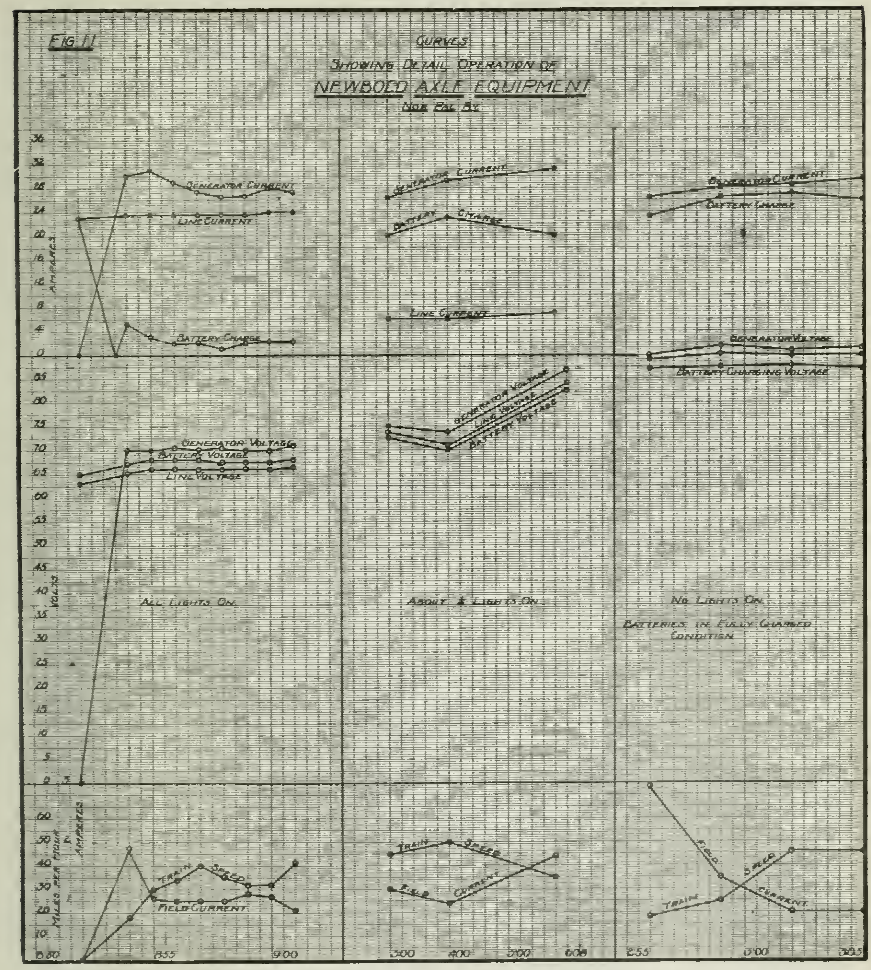


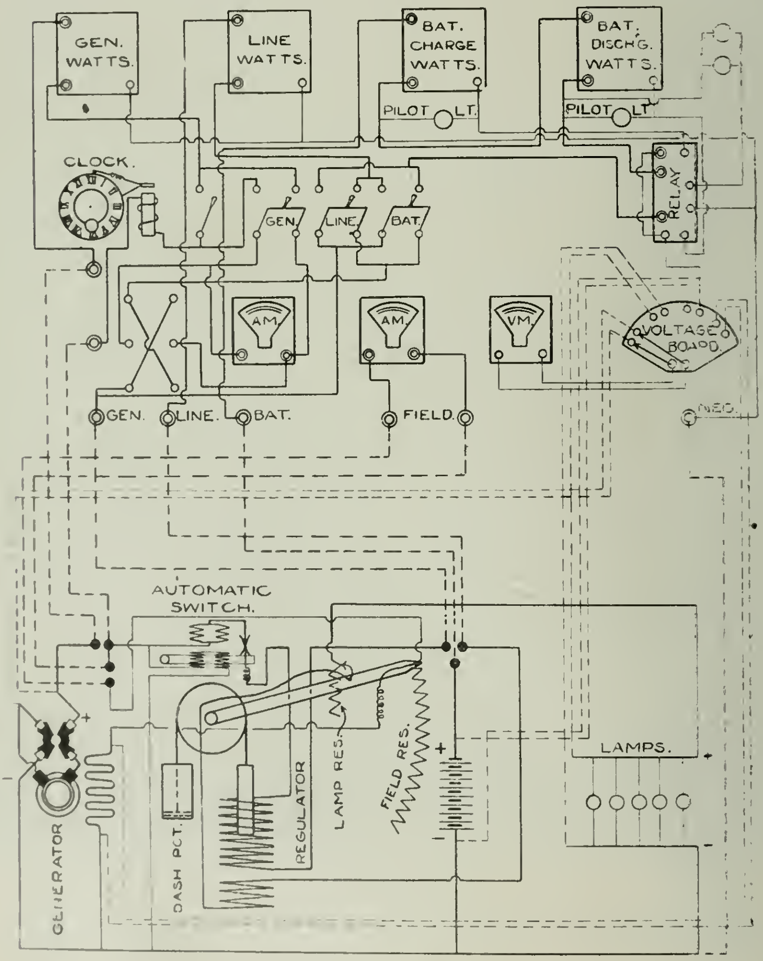
Fig 11

Curves
Showing Detail Operation of
NEWBOLD AXLE EQUIPMENT
Nor Pac Ry

hold oil so that it is asserted that the oil need not be changed oftener than once in several months. The generator case is enclosed, but is provided with hand holes and removable plates for inspection and repairs, and two brushes are arranged on the forward side of the commutators so as to make them quite accessible. The pole-changer is different from that of the Consolidated equipment, more particularly in being a clutch pole-changer which is caused to throw a switch in one direction when the generator armature rotates in one direction, and to reverse the switch when the

FIG. 12.

TEST CONNECTIONS,
NEWBOLD AXLE EQUIPMENT.



armature rotates in the opposite direction. The automatic switch for cutting the generator into circuit and out of circuit at the appropriate critical speed has characteristics similar to those of the Consolidated equipment.

The regulator depends upon the action of a solenoid magnet with its winding in the generator circuit, which operates the rheostat arms against a counterbalance weight. It is not necessary to describe this in detail. The single solenoid and its attached rheostat mechanism serve to control the generator field current for the purpose of maintaining the generator current reasonably constant, and also to control certain resistance sections which are thrown into the lamp circuit when the batteries are being charged, thus maintaining the lamp pressure reasonably constant.

In Fig. 12 is shown the arrangement for testing this outfit, the lower part of the diagram representing the axle driven set with its regulator, battery, lamps and appurtenances, and the upper part of the diagram indicating the testing instruments. The dotted lines intervening are the leads for connecting the instruments. The battery on this car consisted of 32 cells of E 13 chloride accumulators, 240 ampere hours capacity each.

The results of this test include the following: The duration of the test during the run from St. Paul to Portland was 74 hours. The train was above critical speed and the generator operated for 53 hours, and the train was below critical speed so that the generator did not operate for 21 hours. The lamps were lighted 35 hours. The battery was under charge 39 hours. The total generator output was 105 kw. hr., the lamp consumption was 54.3 kw. hr., the battery charge was 56 kw. hr., and the battery discharge was 9.7 kw. hr. The power absorbed from the axle with the train running at 60 m. per hr. was 3.4 HP.; and the average efficiency of the run figured as the ratio of power put into the machine, to the lamp consumption was 40 per cent.

On the return trip, the duration of the test was 66 hours, of which the generator was operating 51 hours and not operating 15 hours. All lamps were lighted during 34 hours, and the battery was receiving charge for 32 hours. The generator output was 95.5 kw. hr., the total lamp consumption was 55.7 kw. hrs., the battery charge was 42.5 kw. hrs. and the battery discharge 10.7 kw. hrs. The efficiency of this run was slightly over 45 per cent

Excessive overcharging of the battery is here again evident, and it would have served the purpose amply, if the regulator had been readjusted to reduce the generator current as much as 25 per cent. The overcharging of the batteries not only reduces very much the efficiency of the outfit in operating, but it also seriously reduces the life of the battery. With a regulator designed to maintain a constant generator current, it will be noted that if the regulator is set for 28 amperes, as was the case with this Newbold equipment, and the lamps are consuming 24 amperes, then in the instance of this particular equipment about 3 amperes go to the battery and the additional ampere goes to the field of the generator; while when the lamp current is decreased to 5 amperes the battery current increases to nearly 23 amperes; and in the day-time the battery consumes all of the generator current except that supplied to the field windings.

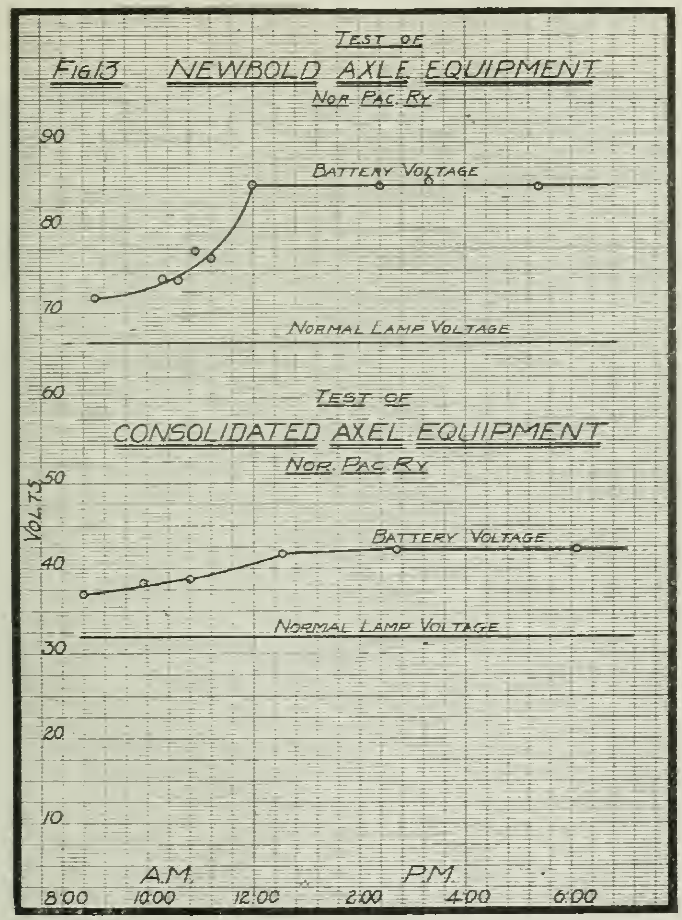
It is also to be noted that the line voltage maintained by this equipment varies almost directly in proportion to the variation of the battery voltage so that the lights are subjected to very considerable fluctuations of voltage. In this instance the fluctuations were as great as four volts under conditions of varying speed, with lights all on, and they were as great as 15 volts with varying speed and a portion of the lights on. This fluctuation of voltage is entirely too great to be satisfactory; and in fact is ruinous to the lamps, besides being very annoying to the passengers.

In connection with the aforesaid remarks about the overcharging of batteries, Fig. 13 shows the day battery voltages on the cars equipped respectively with the Consolidated and the Newbold equipments. From these it will be observed that the battery of the Consolidated equipment was fully charged by 12:30 P. M., and the battery of the Newbold equipment was fully charged by noon. The extended additional charge given throughout the afternoon by each of these equipments wasted power and deteriorated the batteries. An overcharge for a short time occasionally is a good thing, for the purpose of keeping the battery in the best condition, but an overcharge of a half dozen hours every day at the normal rate of charging is sure to cause the rapid destruction of battery capacity.

A similar Newbold equipment on the dining car "Hannibal" of the Chicago, Burlington & Quincy Ry. was also tested. The generator in this equipment was arranged for a full load of 75 amperes at 30 volts. The dining car operated on a short run, and consequently the equipment was under conditions where it must maintain itself under extremely variable service on account of the difference of the hours of lighting in the different times of the year; that is, in the winter months it must maintain the lights on the run and must also furnish light for an hour or two hours while standing in the yards at the terminus. On the other hand, in the summer months the lights are turned on for only about 1.5 hours altogether. The run is of about 100 miles from Chicago to Mendota, Ill., and return, leaving Chicago at 6:10 P. M. and arriving at Mendota at 8:05 P. M., and leaving Mendota on the return trip at 5:56 A. M. and arriving at Chicago at 8 A. M. The car had been put into service with this equipment about two months before the test, which was made in May, 1906. The same tests were made as in the other instances, but the instruments had to be located somewhat differently on account of the meagre space in the dining car. Three round trips were made in this test; two under the normal operating conditions of that date, and one trip was made with the lights operated on a schedule which would approximate conditions in the winter months. The car had never been operated with this equipment during the winter months.

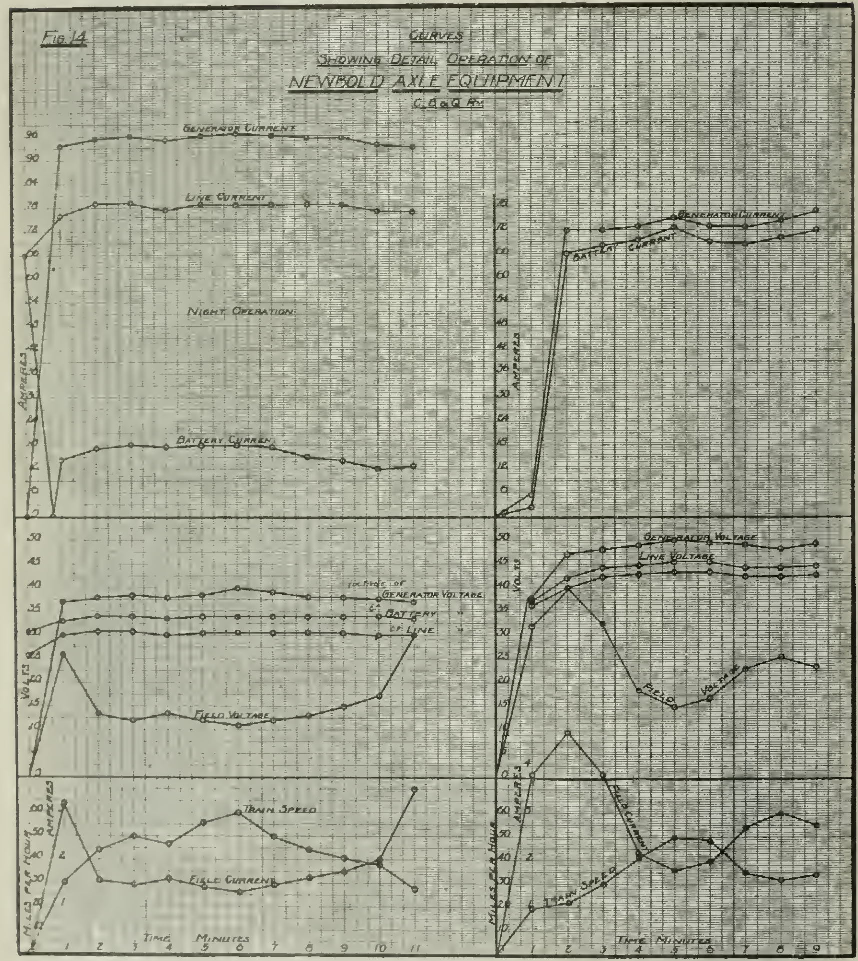
The duration of the first outward trip was 3 hrs., 50 min., the generator operating 3 hr., 22 min. The total generator output was 8.64 kw. hr., the lamp consumption 5.24 kw. hr., the battery charge 3.82 kw. hr. and the battery discharge 1.2 kw. hr

FIG. 13



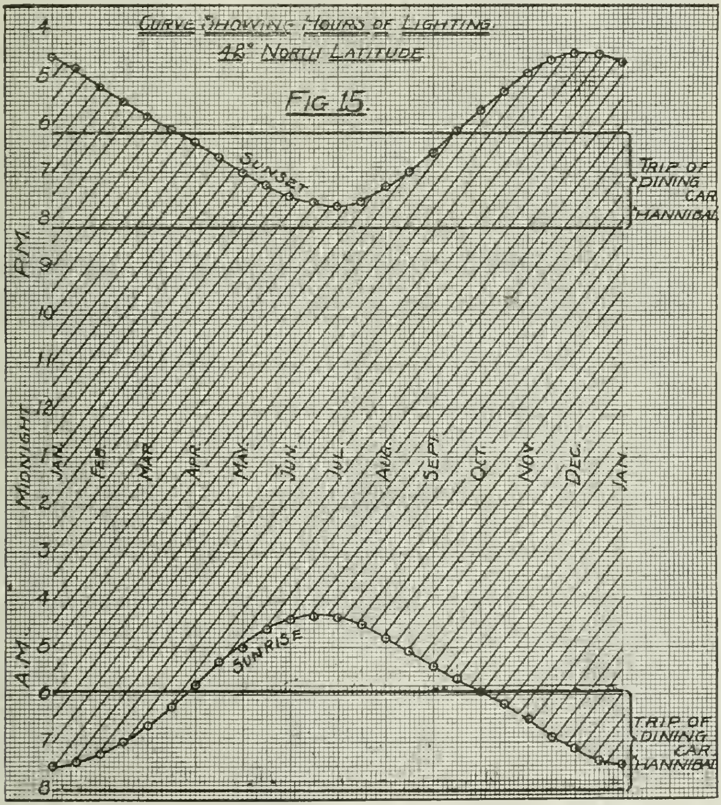
On the return trip the duration of the test was 3 hr., 50 min., during which the generator operated 3 hr., 15 min. The total generator output was 9.36 kw. hr., the lamp consumption was 6.26 kw. hr., the battery charge 3.86 kw. hr. and the battery discharge 1.6 kw. hr. The efficiency of the run was nearly 45 per cent.

In Fig. 14 are given the typical results of this test. They show a better relation between the battery charge and the discharge than in the other instances, but the test taken under winter conditions shows that the regulator would require to be readjusted for winter conditions for the purpose of giving the battery sufficient charge to enable it to support the lamps during the long stands at



the ends of the trip. This change in the adjustment of the regulator, however, is very easily accomplished and requires relatively little attention on the part of the electrical engineer of the road.

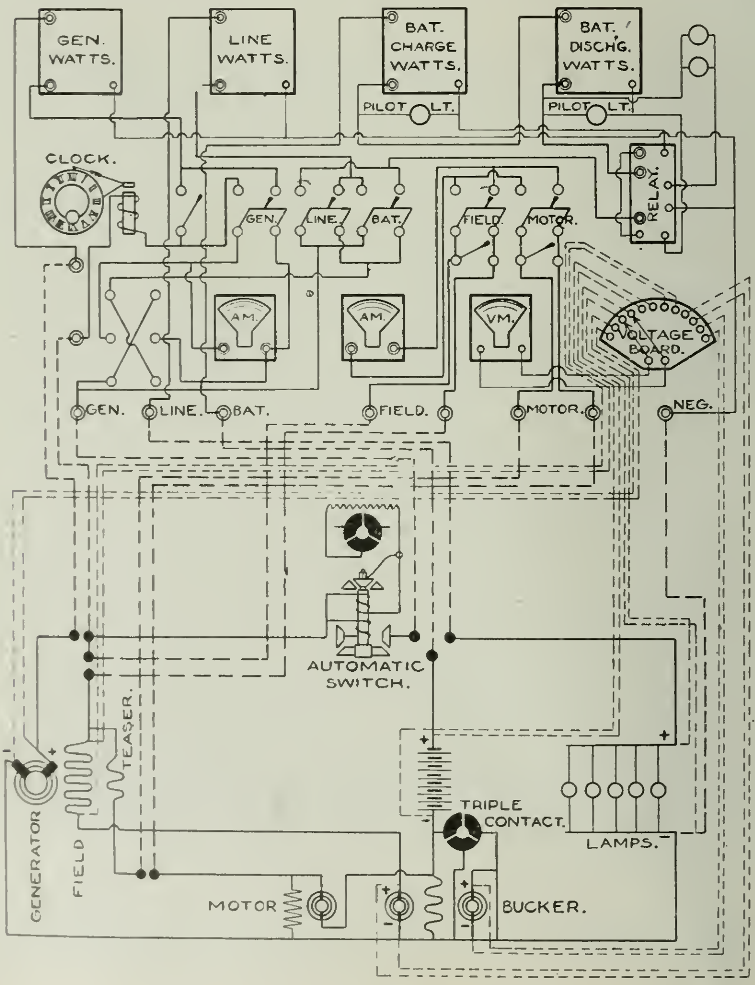
In Fig. 15 are illustrated the difference of the conditions under which the car runs during the different parts of the year. It will be seen from an observation of this chart that during six months of the year the run of the car is substantially wholly within the periods of dusk, while the remaining six months of the year afford a good proportion of daylight, especially in the morning run. Indeed, during June and July very little artificial light is needed in the car for the morning run. The cross-hatching in Fig 15 indicates the time during which the lamps should be lighted, this time being supposed to include the period from one hour before sunset to one hour after sunrise, at every day in the year. The length of the period of all-night service varies from 10½ hours at a minimum in June to 17 hours at a maximum in January, which is an increase of nearly 70 per cent. in the total hours of all-night lighting in January over that for June. In the case of a special car like that of the dining car "Hannibal" the ratio is even greater, as may readily be observed by examining the chart. These cases point



to the idea that it is important where axle driven equipments are used, to plan to change the adjustment of the regulators at certain intervals in each year, for the purpose of preserving the batteries and saving power, and yet furnish ample charge to the batteries to always meet emergency conditions.

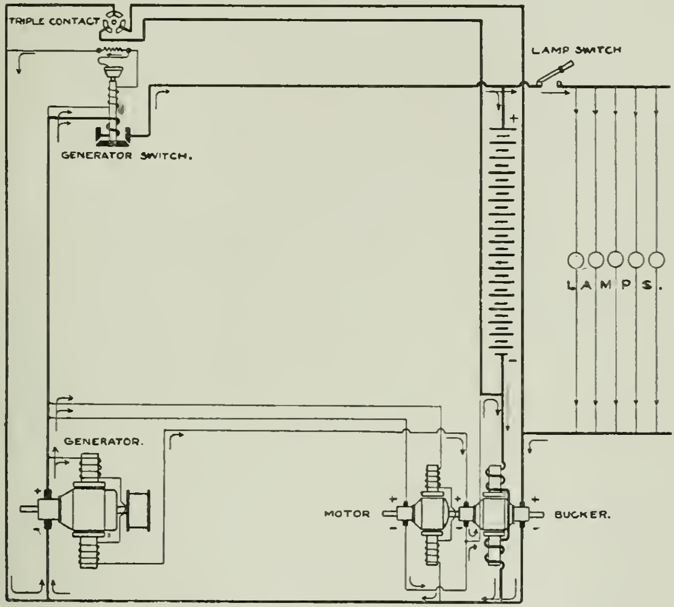
It is to be noted farther that in the instance of the car "Hannibal" the wiring of the car was not sufficient to carry the current of the low potential lamps without an excessive loss. This is indicated by

Fig. 16.
TEST CONNECTIONS,
BLISS AXLE EQUIPMENT.



the great difference between the curves in Fig. 14 illustrating generator voltage, battery voltage and line voltage. Also, the battery is too small for the service, and in fact the 16 cells of the battery of 336 ampere hours each were charged at a rate much exceeding their normal charging rate.

WIRING DIAGRAM OF BLISS EQUIPMENT SHOWING ARRANGEMENT OF BUCKER.



An equipment of the Bliss system was also tested in a run on the Northern Pacific Ry. The method of control in this system is different from the others, as heretofore remarked. The equipment tested in this instance was arranged with a gear drive though it is my understanding that the gear drive has been since replaced by a belt drive. The generator has four poles. It was suspended inside the truck and geared to the axle by means of a driving gear mounted on one end of a split quill surrounding the axle. This quill was driven from the axle by means of four driving springs connected to a dog with two arms, and the dog was secured to the axle. The quill was supported by two sets of roller bearings comprised within the generator frame so that none of the weight of the generator and quill came directly upon the car axle but was all supported by the truck frame. Plenty of clearance was provided between the quill and the axle, so that there seemed to be no inherent difficulty with this mode of operation; though the spring drive did not prove to be sufficiently durable under the conditions of the particular installation.

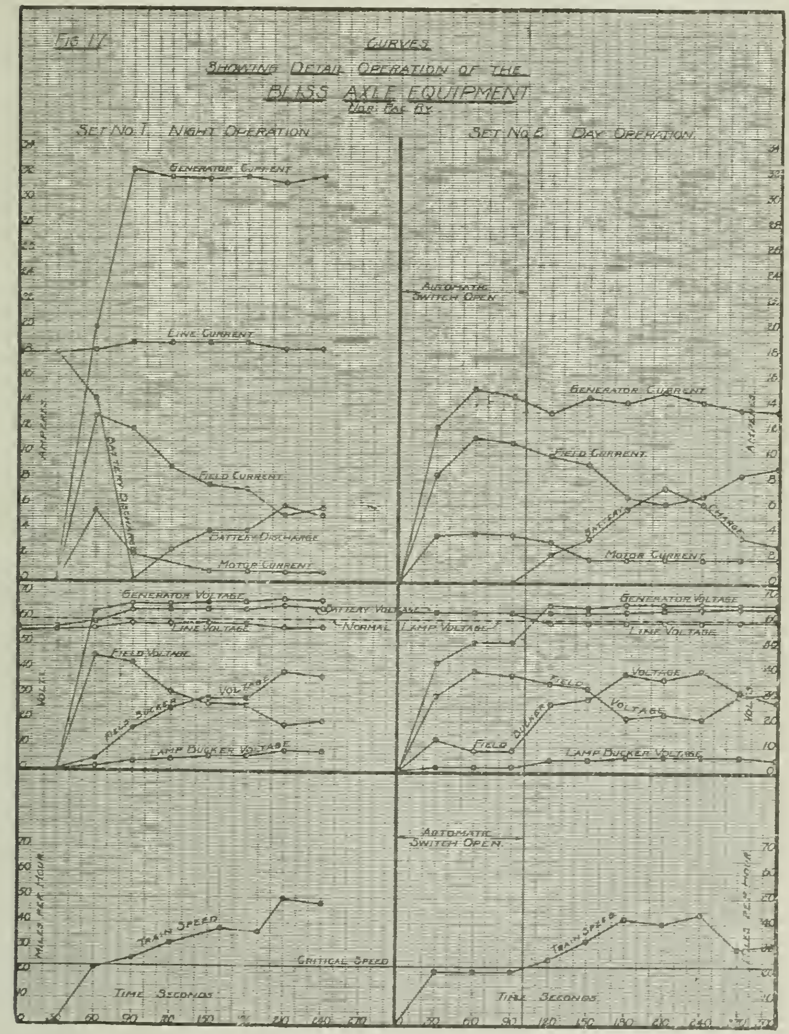
The regulator of the apparatus is unique. Instead of the use of a variable field rheostat, a variable electromotive force is utilized to control the current in the field circuit of the generator. This is accomplished by means of an auxiliary bucker armature driven at substantially constant speed by a small direct connected motor. The excitation for the field within which this bucker armature rotates is developed by the battery charging current, so that the electromotive force set up by the bucker armature is proportional to the battery charging current.

Assuming that the charging current flowing into the battery is proportional to the rise in the generator voltage above the normal battery voltage it will be seen that this arrangement affords means for varying the electromotive force of the generator so that the battery charging current will remain substantially constant for a fixed speed, regardless of the number of lamps burning. When the train speed increases, the generator voltage will normally increase, thus causing a proportionate increase in charging current, but this causes an increase of the bucker electromotive force, thereby reducing the field current and partially compensating for the rise in train speed; and *vice versa.* Left without other precautions this arrangement would result in a considerable change of the lamp voltage when the battery changed from the conditions of discharge to the conditions of taking a charge, at the instant that the generator comes into circuit at the critical speed of the machine, but this is compensated for by placing another winding on the bucker armature which is arranged to introduce a counter electromotive force in the lamp circuit of the proper value to compensate for the change due to the alteration from discharge to charge conditions. This winding, of course, is of low resistance and large carrying capacity; and it is short circuited by an automatic device when the lights are being supplied by current from the battery and no regulation is necessary.

The battery used with this equipment comprised 32 cells of the National type, each of 180 ampere hours capacity. The pole-changing device consisted of an arrangement for allowing the brushes to rotate with the commutator for one-quarter of a revoultion upon the reversal of the direction of the rotation of the generator armature. The generator being a four-pole generator this puts the brushes in positions of like polarity, whichever direction the generator runs.

The wiring of this outfit is quite different from the wiring of the other outfits referred to, but the same general arrangements were utilized for making the test. Fig. 16 shows a diagam of the arrangement, the lower half of the diagram showing the apparatus to be tested and the upper half showing the instruments used, while the dotted lines connecting the two represent the leads running between the instruments.

The test of this equipment was made in the run from St. Paul to Portland. The total duration of the test was 74 hr., during which the generator operated 49.5 hr. and the train was below the critical speed and the generator was not operating 24.5 hr.; the total generator output was 57.9 kw. hr., the lamp consumption was 28.4 kw. hr., the battery charge was 8.5 kw. hr., and the battery discharge was 7.3 kw. hr. In this instance the battery charge perhaps



does not have sufficient margin over the battery discharge and a correction of this condition should perhaps be made. The average efficiency for the trip was about 30 per cent.

In Fig. 17 are shown typical results of this test, from which it will be observed that the lamp regulation is unusually good, the voltage of the lamps changing only from 56 volts to 58.5 volts as the train changed from a standstill to a speed of 50 miles per hour. The battery charge is independent of the number of lamps burning, but does depend upon the train speed, being zero at 25 miles per hour and gradually rising with the train speed to a value of 8 amperes with a train speed of 50 miles per hour. The battery charging current, the field bucker voltage and the lamp bucker voltage each increase directly with the train speed, while the field current and the motor driving current vary inversely with the speed. The method of regulating brings about a nearly constant generator current which is due to the fact that the battery current increases as the train speed rises, but the field current decreases, and these substantially compensate for each other. There is a fault in the apparatus which is shared by the other axle-machine systems: namely, that they do not sufficiently maintain the uniformity of lamp voltage when the conditions change from those of a depleted battery to those of a battery fully charged. The manner of charging the battery at a rather low rate from one end of the run to the other, except when the generator is not operating, is advantageous, however, and the uniformity of lamp voltage is to be particularly commended.

It was expected to test the operation of one or two other types of axle driven equipments on the Northern Pacific Ry., but they were not ready for service within the time available for executing the work, so that no other axle driven equipment besides the two Consolidated equipments (respectively on the Northern Pacific and Burlington roads), the two Newbold equipments (respectively on the Northern Pacific and Burlington roads), and the Bliss equipment were given actual tests. Other equipments were rather closely observed in connection with their operation on certain roads.

PLAIN STORAGE BATTERY LIGHTING.

A test was made of plain storage battery lighting in connection with its operation on the "Burlington" railroad. This was made on a run between Chicago and Minneapolis. Each car of the train was equipped with a battery of 48 cells made by the American Battery Co., each cell having a capacity of 160 ampere hours. The batteries of all cars are charged and discharged together, train lines being run through the cars, and the charge is given to the batteries at the terminal stations, Minneapolis and Chicago. The equipment is extremely simple, has no regulating devices or complicated mechanism in the circuit. A charge is given to the batteries from a stationary charging plant during the day at Minneapolis, and this is followed by the discharge required to light the lights on the train during the night run to Chicago. At Chicago the batteries are again charged during the day, and are discharged in lighting the train during the night run in the return to Minneapolis. A gasoline engine generator set is used at Minneapolis for the charging, and as soon as the train is backed into the yards in the morning the connections are made to the train and the charging begins without removing the batteries. Except for an interval from 12 to 1, the batteries are charged continuously from 8:30 A. M. to 5:30 P. M., using a current of about 40 amperes to the train of four cars. At Chicago the batteries are charged by a steam driven generator.

In testing this equipment, switches were placed in the battery circuits of each car so that an ammeter could be inserted to measure the current flowing. Readings of current and voltage were taken for each car at 15 minute intervals. The results given in the following table are the averages of three separate discharges which were tested:

Chair Car No. 501.

Total lamp consumption for 3 one way trips	17.94	kw. hr.
Total battery charge 3 days	38.6	kw. hr.
Watt hour efficiency of battery	46.5	per cent.

Pullman Car "Pantheon."

Total lamp consumption 3 one way trips	20.9	kw. hr.
Total battery charge 3 days	45.7	kw. hr.
Watt hour efficiency of battery	45	per cent.

Pullman Car "Apollo."

Total lamp consumption 3 one way trips	26.1	kw. hr.
Total battery charge 3 days	51.9	kw. hr.
Watt hour efficiency of battery	50.3	per cent.

Chair Car No. 4151.

Total lamp consumption 3 one way trips	17.4	kw. hr.
Total battery charge for 3 days	31.5	kw. hr.
Watt hour efficiency of battery	55	per cent.

The batteries were old ones and had been operated in this service for several years, which fact accounts for the rather low efficiencies. They were somewhat overcharged each day, but not more than is desirable to prevent the plates from getting into bad order. The operation of this equipment is quite satisfactory from the point of view of the passengers. The lights are connected to the newly charged battery at the beginning of the trip and make a good showing on account of brilliancy, while later in the night when the voltage falls as the battery discharges, the need of the lights is not so great.

CONCLUSION.

In considering the comparison of these several methods of operating, it is to be noted that the first essential is to provide a satisfactory and safe light which will not interfere with the operation of the train, and a great many considerations enter into the account which are not necessary to refer to when dealing with the affairs of ordinary electric lighting concerns. Each of the above named types of equipment have certain advantages and disadvantages for service; but in each instance the success of the equipment lies largely in the hands of the operating department of the railway, provided the people supplying the apparatus have properly installed it and seen to it that the car wiring is right.

The simplest method of any is undoubtedly the straight storage equipment, but it has the disadvantage of requiring expensive charging stations for charging the batteries at the terminals; and it is not applicable to long runs overland. It is most economically operated on short runs where there is heavy traffic and a large number of cars are equipped. Even there it is doubtful whether it can hold its own against the axle drive.

The Chicago and Northwestern Ry. is now making some trials in its cars, of the use of arc lamps operated from primary batteries, but this arrangement does not possess the qualities required for success.

The steam driven generators are probably next in the order of simplicity, but they have the disadvantage of requiring considerable attention. The Chicago, Milwaukee & St. Paul Ry. and the Chicago & Northwestern Ry. have partially overcome this objection by training their baggagemen to operate the engine sets in addition to looking after their regular duties. But the greatest disadvantage of this system relates to the inconvenience that comes from the necessity of operating the train as a unit. However, the equipment is very satisfactory when applied to trunk line trains operating for definite runs, and especially to the so-called overland trains with very long runs and insignificant changes of the cars between terminals.

The axle equipments have the disadvantage of apparent complexity; but they possess the very large advantage of providing for the lighting of each car as an independent unit in itself, which makes this method of lighting feasible for application to individual cars on miscellaneous lines as well as to cars in trains operating as a unit. In fact it may be said that there are a great proportion of cars for passenger service, such as dining cars, parlor cars, mail cars, many sleeping cars, as well as ordinary day coaches, for which this is the only advantageous method of lighting by electricity; and for which it is by all odds the safest and most satisfactory method of lighting. A prime difficulty with the axle drive arises on account of the fact that the railroads have not yet obtained enough equipments to make worth while the organization of a careful force for their inspection and maintenance. This is absolutely an essential feature, and must be brought about before the axle drive equipment can be expected to give reasonable satisfaction. Another difficulty lies in the fact that the manufacturers have not yet put their regulating devices upon a fully satisfactory basis.

The manufacturers are also to be criticized because they have not followed up the installation of their equipment with sufficient care, and have not fully instructed the railway employees in the manner of inspecting and handling the equipments. The operation of axle equipments is intricate, and any railroad entering the field of electric lighting by this means should place the work under the direction of a man who has a clear conception of all the considerations required in the operation of these appliances, and who is also well acquainted with the characteristics of storage battery operation. When this is done, and the manufacturers co-operate properly with the railroads, the axle drive equipments will become a factor of very large importance to the railroads. However, where a railroad buys a few equipments and places them in operation on its cars as a matter of trial, leaving them to substantially take care of themselves, or in the hands of ordinary yard men, it may be expected that the experiment will result in failure and dissatisfaction; and it will also enlarge the misconception which now in some degree exists as to the real merit of these equipments.

The relation of the steam used by the engine driven electric lighting sets and the axle driven sets for a given train is somewhat difficult to fix, but the following figures are approximate. On trains like the "Pioneer Limited," the "Overland Limited," etc., etc., the steam consumption while the electric light plant is in operation, with the steam driven sets, is from 700 to 900 pounds of steam per hour for eight car trains. This makes a steam consumption of approximately 100 lb. per hr. per car on the train. The electric light engine operates from 8 to 10 hours a day, and it may be taken as an average figure that about 900 lb. of steam are consumed per day per car.

In the cars with the axle driven sets the average power absorbed from the axle throughout a run may be set down as between 2 and 3½ HP. per car, depending upon the character of the car and the system considered. For the extended lines overland, this continues for 24 hours out of every day and consequently from 48 to 60 HP. hr. are absorbed from the axle. Assuming that the locomotive can develope each horsepower with 30 pounds of steam per hour, the consumption of steam by the axle driven set amounts to between 1,500 and 1,800 lb. of steam per 24 hr. day, which is from 50 per cent. to 100 per cent. larger than the amount of steam used by the baggage car set. This is offset by the fact that the operation of the set is rendered automatic and requires inspection and testing only at the ends of the trip instead of requiring this attention continuously during the run, and that the consumption of steam per hour is only 0.65 to 0.75 as great as with the engine driven sets.

When the run comprises only the time of a single night, or less, instead of extending over twenty-four hours, the advantage turns distinctly towards the axle driven equipment.*

As before pointed out, one of the features that militates against the best success of certain of the axle driven sets lies in the fact that the manufacturers have not learned to install their apparatus in the best possible manner and are willing to undertake the operation of the sets in connection with cars which are poorly wired. The same fault has been observed in connection with some tests that were made under my direction of two of the types of electric arc headlight apparatus which are now in some considerable use. Such headlight apparatus has been ordinarily installed in what experienced electric light people would call a slovenly manner, while the exigencies of service should require it to be installed in a manner bearing the highest character known in the art.

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* Since this manuscript was written, the writer has received a copy of a careful paper by Mr. O. W. Ott, who discusses this question. The paper was read before the Western Railway Club in April.

DISCUSSION.

President Abbott: During the reading of this paper I was impressed with two facts: One was how desirable the railway people must consider electric light in comparison with gas lamps with which their cars are equipped, to warrant them in going to the great expense implied by this paper in fitting up their trains with such a lightning equipment. The other fact was, in what great luck the passengers are in having any light at all with such equipments as the trains are furnished.

Train lighting is a question of increasing importance, and I think the desirability of electric lighting will be one of the minor but yet important considerations in eventually changing the propelling force of the passenger trains from steam to electricity.

Mr. H. R. King, M.W.S.E.: Mr. Jackson lays considerable emphasis on the point that the manufacturer had considerable work yet to do before train lighting systems would be a commercial success. I think the paper shows that they have expended considerable time and thought in trying to arrive at a satisfactory solution of the problem and with a fair degree of success. Many schemes have been tried with more or less satisfactory results. We had under consideration some time ago a train-lighting device brought to us by an inventor. We were asked to supply the generator. The experimental model was intended for head-lighting, and it was expected that the scheme would be extended to train-lighting if it proved a success in the application to head-lighting. The generator was connected to an ordinary ventilating fan located in front of the locomotive, just below the headlight; the idea being that the fan would revolve with considerable power when the train was under way. Suitable controlling apparatus was installed to compensate for speed variation. The model was placed on one of the Pere Marquette trains and was tested for some time, but I do not know with what success. The scheme was eventually dropped. It was somewhat novel, and shows to what extent inventors have gone to solve the train-lighting problem.

Referring again to the subect of the paper, I would be much interested in a comparison of the regulation of the three systems: the turbine driven outfit, the reciprocating engine outfit, and the axle driven outfit. How close is the regulation of these various schemes, considering the regulation as the fluctuation of the voltage at the lamps? The maintenance of the lamps depends upon the regulation, and is an important factor in determining the best system.

The question of vibration is one which the author points out as being touched upon in a paper read before this society some time ago. As the Westinghouse engine is single acting, the question might be raised as to what effect a double acting engine has as to vibration.

The author of the paper states that the C. & N. W. Ry. Company is now experimenting with arc lamps for train lighting. It would be interesting to know what the difficulties are. It is evident that an arc lamp suitably constructed would be much less affected by voltage fluctuation than the incandescent lamps and would allow more latitude in the design of the lighting system on account of the permissible fluctuation. I believe an arc lamp can be constructed that will successfully operate under the normal vibration of the train.

President Abbott: Along the line of what Mr. King has just been saying, I should also think that Tantalum lamps would work better than carbon filament lamps on account of being less affected by variation in voltage.

Mr. Bohan, (N. P. Ry.): One evident disadvantage of the steam equipment, not found with axel devices, is the continuous drain on the locomotive on grades and under such conditions as bad track, weather, etc., where it is necessary to run at low speeds. In the case of the axel equipment, when the train is running at a speed lower than the cutting in speed of the axel generator (which is a frequent occurance), the lighting load is carried entirely on the battery, and, in going down grades, of course, no power from the locomotive is used whatever.

During the past winter we have had several severe storms on our line in Dakota and Montana, with temperatures varying around fifty degrees below zero, where we have not been able to maintain the average cutting in speed of axle generators and have found it necessary to shut down the dynamo engine to haul the train. We have also found it decidedly advantageous, on account of the drain on the boiler, to shut down the dynamo engine to make running time on high speed trains in good weather, where extra cars have been addd, which taxed the power to its utmost.

Another disadvantage with the steam-operated dynamo (in the baggage car at least) is the necessity of getting the dynamo as near the locomotive as possible to avoid carrying steam through long lengths of pipe, and steam connections. It is frequently undesirable to place the dynamo car next to the engine, and some roads are carrying steam back as many as three cars. I do not think it exaggerating to state that in such cases the steam loss is frequently sufficient to light a number of cars in a train.

Another matter of considerable importance is the maintenance of dynamo steam couplings, throttle valves and reducing valves on locomotives. This apparatus requires a great deal of attention, particularly in bad water districts. Each additional appliance on a locomotive means more work for the repair man, which is to be avoided as much as possible in these strenuous days of railroading. The steam outfits on the other hand, are ideal in that the source of power is centralized in a simply constructed unit, requiring very little repairs. Electric and mechanical failures are rare exceptions, and light is practically assured at all times when steam is available.

Results thus far obtained from individual axle devices indicate that they are not the solution of the problem, on account of the amount of equipment required, large first cost, expensive maintenance, and other well known objections. The source of power from the axle, however, is ideal, and the ability to dispense with train electricians is another point decidedly in their favor. A system that will combine the virtues and eliminate most of the objections found in both the steam and individual lighting outfits would, therefore, appear to come nearest to solving the problem. I believe that such a system should consist of a single head end generator, of ample capacity to light an entire train, combined with sufficient, carefully selected storage batteries, properly distributed. The machine should be located inside the car and mounted on the truck. Mounting the generator on the truck below the body of the car is a mistake for several reasons: Repairs to truck are hampered, the apparatus is inaccessible for repair, and the machine and wiring are exposed to weather, flying particles, snow, and dust, which produces a large number of failures with the present outfits. The machines can be located inside the car and mounted on the truck by means of a cast steel or other metal framework extending through the floor, ample clearance being provided to take care of movements of the car body and truck. Openings in the floor can be suitably housed by means of flexible diaphragms. This method of mounting is entirely practicable without material changes in present forms of standard car and truck construction. The drive can be either belt or chain.

The matter of selection of the proper battery to suit the conditions cannot receive too much attention. Every man who has been up against the battery problem will attest to the fact brought out by the writer of the paper, that batteries used in connection with all train lighting devices are subject to many abuses, principal of which are the lack of attention by terminal men, overcharging and overdischarging. The first can be overcome only by strict discipline; the other two can be largely overcome by careful selection, and suitable charging facilities, which are available at small cost. The number of batteries and their size should be reduced to a minimum. A battery should not be put on a car unless operating conditions absolutely require it. Many electric lighted trains are, in my opinion, "over-batteried." With a view of overcoming this condition, which exists to a certain extent on our line, we have equipped one of our North Coast Limited Trains with two large batteries of fifty-two cells each—one located under the baggage car and one under the observation car. The combined battery is of sufficient capacity to light the entire train for a period of five hours in case of shut-down to the dynamo. The train, with the exception of one sleeper cut out at Livingston during the summer months, and one sleeper cut in at Seattle and Tacoma, respectively, west bound, and one sleeper cut in at Butte, east bound, runs between terminals in tact. Two batteries are used in order to light the two ends of the train when cutting cars in or out. The batteries are controlled by an automatic loop and battery switch, which cuts batteries in and out as required and makes loop on the three-wire mains when dynamo is cut in. Circuits are arranged to charge two halves of each battery in parallel at 104 volts (lamp voltage) through a fixed resistance of one ohm. Batteries are cut in by train electricians after the lighting load is sufficiently low to take on charging load, and are cut out when fully charged, condition of charge being determined by voltmeter test. The charging on the road entirely eliminates overcharge, overdischarge and terminal charging. Cutting out the terminal charge is very advantageous in that it permits of the train being placed at any part of the yard which may be available on arrival of train for the purpose of cleaning, repairs, etc., and also does away with the use of steam, which is always to be avoided. Another thing which is gained by having but the two batteries is that we are able to use any of the cars in the train (other than the baggage and observation cars) in any other trains not electric lighted without removing the batteries to prevent their being neglected. This equipment has been in service for several months without a failure and thus far has given excellent satisfaction.

It is pleasing to note that the railroads are alive to the importance of an efficient, clean and safe lighting system for their trains and are sparing no expense to determine what will best fill their requirements, both as to quantity and kind of equipment. Electricity seems to have the best of it, as far as kind of light is concerned, and, with the aid of the several reliable concerns employing some of the best talents in the country who are working on electric lighting systems, we can expect the art to shortly reach a high state of perfection.

Mr. J. R. Cravath, M.W.S.E.: There is one aspect of this train lighting problem which has not been touched on this evening, and that is the question of what use is made with the light that has been produced. Where lighting costs as much as it evidently does, judging from the figures given in Prof. Jackson's paper, it would seem to be worth while to give a good deal of attention to utilizing it to the best advantage after once getting it in the top of the car. As a matter of fact, I do not know of any place where all the fundamental principles of illuminating engineering are violated more than in car lighting. In fact most of the light could be produced with about half the energy, and of course that means half the equipment, all along the line. It is a question of very simple illuminating engineering to get the light delivered down where the passengers want it instead of lighting up the top of the car only.

Prof. E. H. Freeman, M.W.S.E.: I recently saw some figures that may be of interest in connection with the comparison of the illumination produced by Pintsch gas and by arc lights. In this case I do not know whether the arc lights were supplied from primary batteries or from some other source. The illumination was measured on a horizontal plane at the height of the backs of the car seats, and for the Pintsch lights averaged about 0.75 of a foot-candle, while for the arc lights about 2.5 foot-candles.

CLOSURE.

Mr. W. B. Jackson, M.W.S.E.: As I have been called upon to read this paper on account of the unavoidable absence of my brother, D. C. Jackson, who is the author, I will take upon myself an answer to the inquiries that have been made.

In regard to the lamps that are ordinarily used, they are commonly of low voltage and consequently are not so much affected by the vibrations as if thy were high voltage, although, of course, any lamp that is installed in a running railroad train must be seriously affected by the vibrations, I question whether any one knows how serious an effect on the life of the lamps is caused by the train vibrations and shocks.

It has been suggested that the author of the paper has found much fault with the apparatus made by the train lighting and axle lighting manufacturers, but it seems to me the contrary. In the paper he extols rather than depriciates the work of these manufacturers, and what is criticized in the paper is that the manufacturers have been willing to allow their apparatus to be badly installed, and have allowed it to be installed in connection with very bad equipments, which has naturally produced a poor impression. The axle driven systems are relatively new devices and must have their troubles worked out in practice. We all know perfectly well that a train lighting system cannot be worked out to a satisfactory point in any factory. It must go on the trains and be worked out in practice and it should be looked after carefully while it is being installed and thereafter. I think one has a right to find fault with the manufacturers when they allow their apparatus to be badly installed and installed in connection with other poor equipments. However, I say, all praise to the people who have been pushing this work ahead.

In regard to the inquiry about the relative voltage regulation of the steam driven baggage car sets compared with the axle driven sets, it is obvious that the regulation of the former must depend considerably on the attention bestowed by the dynamo attendant, but it is not likely to have as many sudden changes, which affect the brilliancy of the lamps in a disconcerting manner as are noticeable in most of the axle-driven equipments. However, a scrutiny of the curves displayed in this paper will prove to any one that some axle driven sets are now affording a fidelity of regulation that should satisfy the most fastidious patron.

THE NATURE OF TRUE BOILER EFFICIENCY.

By Walter T. Ray and Henry Kreisinger, Mems. w.s.e.

Presented Sept. 18, 1907.

The substance of this paper is mostly an abstract from a bulletin now being sent to press by the Steam Engineering Division of the Technologic Branch of the U. S. Geological Survey. The authors wish to make special acknowledgement to Prof. L. P. Breckenridge for many valuable suggestions relating to the subject under consideration, and his criticism of some of the parts in this paper. Due credit must also be given to our co-workers C. E. Augustine, F. I. Bird and C. J. Fletcher for their conscientiousness in helping with the experiments.

Early in the routine work of the Steam Engineering Division of the U. S. Geological Survey, it was realized that the boiler tests made for the purpose of determining the value of coal for steaming purposes meant little unless the boiler performance were subtracted or divided out, so as to get to the efficiency of the grate and furnace. When attempts were made to separate the performance of the boiler from that of the furnace, it was found that little was known of either, which fact made the separation impossible. It was therefore decided to conduct laboratory experiments on small boilers, with the object of determining the laws which govern heat absorption by boilers.

The purpose of this paper is to present the more important results of these experiments, and to offer a few formulated laws governing the rate of heat absorption by boilers. The outline of these experiments, and the results of the early tests were presented by Prof. L. P. Breckenridge before this society March 20, 1907, and are recorded in Vol. XII of the Journal, w.s.e.

Heat Transmission.

Heat travels from any hot body only to bodies at lower temperature, therefore, any boiler can absorb only that heat which is above the temperature of the water in it; heat below this temperature will not flow into the boiler water and therefore is not available for absorption. Commercial boilers absorb only part of the heat which is available for them; the percentage of the available heat which is absorbed by the boiler is called the true boiler efficiency. This efficiency depends somewhat on the way the heat is presented to the boiler, but chiefly on the construction of the latter. The true boiler efficiency is then defined as the ratio of the heat absorbed by the boiler to the heat which is available for it, counting only that heat available which is above the temperature of the boiler water.

In any steam generating apparatus the heat is evolved by the burning of fuel in the furnace, and is then transmitted through the space and through the water heating plates into the boiler water. The path of the heat travel and the mode of the transmission is shown in Fig. 1.

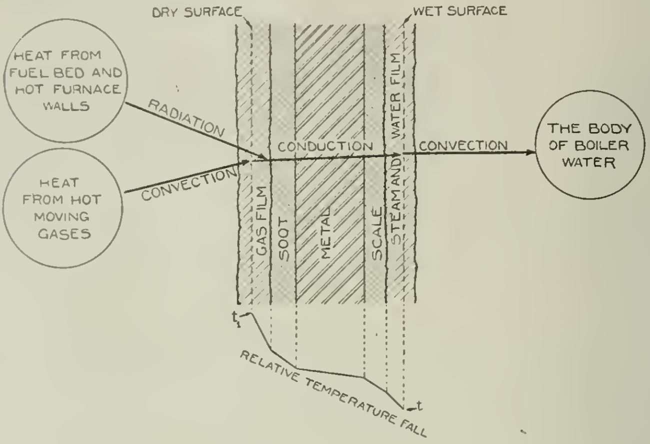

FIG. 1.
DIAGRAM SHOWING THE PATH OF HEAT TRAVEL FROM SOURCE OF HEAT TO BOILER WATER

In practice, the water heating plate of the boiler is always covered on the outside with a coating of soot, and on the inside with a layer of scale or mud. Just on the outside and entangled in the small recesses of the soot coating, is a dense film of gas which adheres to the solid. The density of this gaseous film decreases outwards from the solid layer of soot. It is somewhere within this gaseous film where the dry surface of the water heating plate can reasonably be assumed to exist. There is a similar film of steam and water, adhering to the layer of scale on the inside of the boiler which film can be considered to contain the wet surface of the heating plate.

In the diagram it is shown that heat is communicated to the dry surface of the water heating plate mainly in two ways:

(a) by radiation from the hot fuel bed and furnace walls.

(b) by convection from the moving gaseous products of combustion. By convection is meant here the process of displacing cold molecules from the adhering film of gas by hotter ones from the moving mass of hot gases.

From the dry surface of the heating plate, the heat is transmitted through the layers of gas, soot, metal, scale, and steam to the wet surface purely by conduction. From the wet surface the heat is carried into the body of the boiler water mostly by the convection of the circulating water. The retardation of any one of these three modes of heat travel lowers the efficiency of the boiler.

It has been said that the dry surface of the water heating plate may be considered as being somewhere in the adhering film of gas. This statement is more correct when it refers to the heat communicated by convection than to the heat imparted by radiation. In the latter case the greater part of the heat passes through the gas film directly to the soot, because gases are to a great extent permeable to the radiant energy.

As the adhering films of gas and the film of steam and water may be, and very likely are of considerable thickness, the heat must pass through part of the thickness of the film by conduction and as both the gas and steam are very poor conductors of heat, the resistance which these films offer to the passage of heat may be even greater than the combined resistance of the soot, metal and scale.

Although this paper is intended to discuss mainly the factors which influence the rate of heat impartation by convection, a brief explanation of the laws of the rate of heat radiation and the rate of heat conduction will help in making clear the whole matter of heat absorption by the boiler.

The quantity of heat which the boiler receives by radiation from any hot portion of the furnace or the fuel bed may be taken to be proportional to the difference of the fourth powers of the absolute temperatures of the hot parts of the furnace and the soot coating on the boiler plate. This law of radiation is known as Stefan & Boltzmann's Law. Strictly speaking this law applies only to black bodies; however, within the usual temperature range of the boiler furnace it can be applied to boiler problems without any serious error. Mathematically expressed, the net heat transmitted by radiation per unit of area (of hot and cold surfaces) in a unit of time is

$$(1)\ H = C\ (T^4 - t^4)$$

where

C is a constant

T is the absolute temperature of the furnace walls and

t is the absolute temperature of the soot coating on the boiler plate.

It is apparent from this equation that the quantity of heat received by the boiler by radiation increases very rapidly as the temperature of the furnace rises. In boilers where the heat received by radiation is a predominant part of the total heat absorbed, the true boiler efficiency necessarily increases with the rise of the furnace temperature.

The quantity of heat which can be transmitted through a given unit of water heating plate in a unit of time, depends on the difference of the temperatures of the dry and the wet surfaces of the heating plate, and the conductivities of the substance between the two surfaces. This law can be expressed by the following simple formula:

$$(2)\ H = \frac{c}{d}(t_1 - t)$$

Where H is the quantity of heat transmitted per unit of area of the heating plate, c the average conductivity of the substance between the dry and wet surface, d the distance between the two surfaces, t_1 the temperature of the dry surface, and t the temperature of the wet surface.

This law governing the rate of heat transmission by conduction is the same as Ohm's Law used in electrical conduction.

It is evident that with any given condition of the surfaces, the rate of the heat transmission depends entirely on the excess of the temperature of the dry surface over that of the wet surface. For instance, if it is required to transmit double the quantity of heat in the same length of time, the difference of the temperatures of the two surfaces must be doubled. Since the temperature of the wet surface is nearly the same as that of the steam in the boiler and therefore can not be lowered, the temperature of the dry surface must be raised; as it is this dry surface of the heating plate which cools the furnace gases, the rise of its temperature results in the rise of the temperature of the escaping gases. Thus we see that with the same conditions of the heating plate and the same initial temperature of the furnace gases, the temperature of the escaping gases will rise with increasing capacity. Any cause which with the same initial temperature of furnace gases tends to increase the factor $(t_1—t)$, increases the loss up the stack and lowers the efficiency of the boiler by the same amount.

The main causes of the unnecessarily high factor $(t_1—t)$ and consequently the cause of high temperature of the waste gases is the presence of the soot and scale on the surfaces of the heating plate. The heat conductivity of both of these substances is very low, which low conductivity in equation (2) would be indicated by decreasing the value of c, and as the added thickness has already increased d, it is evident that if H is to remain the same, the factor $(t_1—t)$ must be increased. This last consideration shows that it is important to keep the surfaces of the heating plate free from soot and scale.

The heat imparted to the boiler by convection forms in most cases a large percentage of the total heat received. It is therefore very desirable, for the sake of better boiler construction and operation, that the factors which influence the rate of heat impartation by convection be more thoroughly known. Excepting a few experiments done abroad and bearing only indirectly on the steam boiler problem, nothing has been done towards determining these factors. The steam Engineering Department of the U. S. Geological Survey recently started the investigation of this problem, as an incidental feature in its regular work in testing the quality of coals for steaming purposes. These investigations consist of laboratory experiments made on small models of horizontal multitubular boilers. The laboratory methods and the small boilers were taken up because, *first,* it requires small outlay of money to conduct the experiments, and *second,* it is easier on a small laboratory apparatus to control all .the conditions than it would be the case with a large boiler and furnace. It is necessary in work of this kind to keep all the conditions constant.

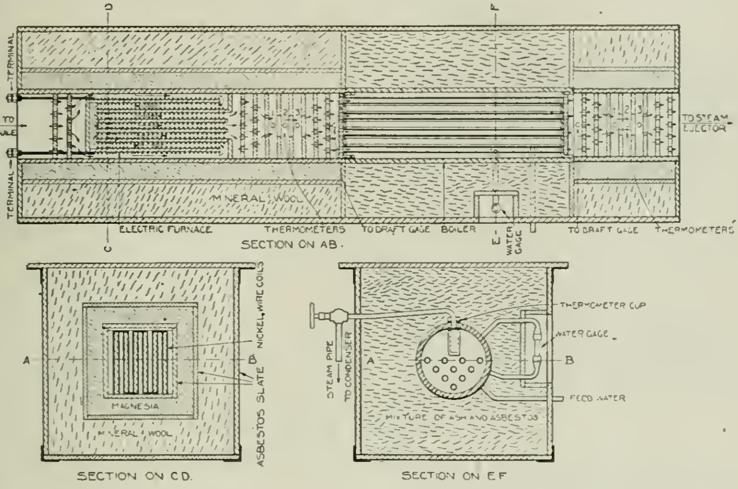

FIG 2.
APPARATUS FOR DETERMINING THE RATE OF HEAT TRANSMISSION THRU BOILER FLUES

Small multitubular boilers were used because they are boilers in the simplest form, the passages of the gas consisting of plain cylindrical tubes. Water tube boilers present much more complicated problems on account of the irregular and variable passages for the gases. The flues were made of thin copper tubes in order to reduce the resistance of the metal to a minimum; as soot and scale were entirely avoided, only the resistance of the film of gas on one side and the film of water and steam on the other was left. An electrical furnace was selected for heating the air, because by its use soot formation and deposition on the heating surface were avoided.

The apparatus consisted mainly of a small horizontal multitubular boiler, an electric furnace, a surface condensor, and a steam ejector for producing draft. The boiler and the furnace were placed within a box which formed the body of the apparatus. The box was built of asbestos slate and filled with mineral wool and magnesia covering. Fig. 2 shows the assembled view of the apparatus.

So far three boilers were used in the experiments. They were made of a standard 4 inch wrought-iron pipe for the outside shell. The heads were made of ⅛ inch thick sheet copper and were riveted to the 4 in. pipe. The flues were ten in number and consisted of thin drawn copper tubing; they were either soldered or expanded into the boiler heads. Fig. 2 shows two cross sections of one of the boilers.

Dimensions of Boiler No. 1.

Length of boiler, outside to outside, of boiler heads	8.28 in.
Actual outside diameter of flues	0.252 “
Actual inside diameter of flues	0.175 “
Thickness of the walls of flues	0.033 “
Total area of the inside cross section of flues.....	0.00167 sq. ft.
Total heating surface of flues	0.31617 “ “

Dimensions of Boiler No. 2.

Length of boiler, outside to outside of boiler heads	8.28 in.
Actual outside diameter of flues	0.313 “
Actual inside diameter of flues	0.230 “
Thickness of the walls of flues	0.041 “
Total area of the inside cross section of flues....	0.002885 sq. ft.
Total heating surface of flues	0.41554 “ “

Dimensions of Boiler No. 3.

Length of boiler, outside to outside of boiler heads	16.125 in.
Actual outside diameter of flues	0.252 “
Actual inside diameter of flues	0.175 “
Thickness of walls of flues	0.033 “
Total area of the inside cross section of flues	0.00167 sq. ft.
Total heating surface of flues	0.6156 “ “

Each of the boilers was equipped with a water gauge glass, a thermometer cup for measuring the temperature of steam, a pipe for feeding the boiler and a pipe for letting out the steam.

The electric furnace consisted of six coils of pure nickel wire, wound around rectangular pieces of asbestos slate which were 9/32 in. thick, 3-7/8 in. wide and 12 in. long. The nickel wire was 0.072 in. in diameter which is about No. 13 B. & S. gauge. There were 51 turns of each coil so that the total length of the wire in the furnace was 204 feet. In most of the tests the coils were connected in series; with high temperatures and high drafts three coils were connected in series and the two threes in parallel. A water reostat was used for adjusting the electrical energy to each temperature and draft. Direct current of 220 volts was used for feeding the furnace. The coils were placed vertically in the front portion of the asbestos slate box with a space of about 5/16 in. between them and so baffled that the air passed along the coils three times before it left the furnace. The arrangement of the coils in the furnace is shown in two views in Fig. 2.

The surface condenser consisted of two concentric copper tubes; the inner one of these was for steam and the outer one for a stream of cooling water. The size of the steam tube was the same as that of the flues of boiler No. 1, and the size of the water tube was 0.3

in. inside diameter. The total length of the condenser was 11 ft. 6 in.

The steam ejector for producing draft was a standard ⅛ in. pipe, placed in the center of a contracted pipe made of galvanized sheet iron which took the gas away from the rear of the boiler.

The asbestos slate box forming the body of the apparatus was 1 ft. high by 1 ft. wide and 5 ft. long. The inside space holding the furnace and the space in the back of the boiler was 4 in. square making the total thickness of the walls of 4 in. The walls around the furnace consisted of ¼ in. thick, asbestos slate lining; next to this was one in. layer of magnesia boiler covering, of 85 per cent magnesia oxide and 15 per cent of asbestos. The remaining space between the layer of magnesia and the outside sheet of the box was filled with mineral wool. The space around the boiler was filled with a mixture of wood ashes and asbestos.

The space between the furnace and the boiler was fitted with eight perforated screens. The four middle screens had in the center a round hole 1¼ in. in diameter. In the spaces between these four screens three thermometers were so inserted that their bulbs were in the center of the 1¼ in. holes. The object of these screens was to concentrate the air around the bulbs of the thermometers in order that its temperature could be more accurately measured. The two screens nearest to the furnace and the two nearest to the boiler had each thirty-two, ¼ in. holes, these being so drilled that the thermometers were perfectly screened from direct radiation from either the boiler or the furnace. A similar arrangement was employed for obtaining the temperature of the air leaving the boiler. Tubes for measuring drafts were inserted on each side of the boiler between the boiler head and the first screen. The front of the furnace was also screened from radiating heat to the outside. Both of the boiler heads were covered with ¼ in. asbestos paper and slate so that only the heating surface of the flues was effective. In Fig. 2 the path of the air through the apparatus is indicated by the arrow heads. The boiler was fed with distilled water obtained by condensing steam from the main boiler of the plant.

The heat absorbed by the boiler was measured by the water evaporated which was condensed and measured. No attempt was ever made to make corrections for moisture in the steam.

The electrical energy used in heating the air was measured by an integrating wattmeter.

Temperatures up to 700 deg. F. were measured with mercurial thermometers which were compared with a standard thermometer calibrated by the Bureau of Standards in Washington. Temperatures above 700 deg. F. were measured by exposed platinum and platinum-rhodium thermo-couples which were calibrated by means of known melting points of pure metallic silver, barium nitrate, potassium chloride, and calcium chloride. A point of 700 deg. F.

was determined by direct comparison with a mercurial thermometer immersed in an oil bath.

Although great care was taken in placing and screening the thermometers and the thermo-couples, considerable difficulty was experienced in the measurements of the initial and final temperatures of the air. With the initial temperature of 1200 deg. F. and 1500 deg. F., the three thermo-couples would at times read as much as 150 deg. F. apart without any apparent reason to account for it. Generally the thermo-couples closest to the furnace read higher than the other two. The only reasonable explanation of this fact was, that in spite of the screens this thermo-couple received some heat by radiation from the furnace, while the one nearest to the boiler lost some heat by radiating it to the boiler. Considerable difference in reading was also obtained if the thermometers or thermo-couples were slightly displaced. The thermometers on the side of the leaving gas, read from 10 to 20 deg. F. apart. It was very difficult to come to any conclusion which of the thermometers or thermo-couples were right and which were wrong. It was thought best to take the average of the three readings at each end. All these difficulties met in the temperature measurements, made the men making these experiments realize that measuring the temperature of gases is a high art.

Before starting a test, the apparatus was brought to the temperature at which the test was to be run. After a test was started all conditions were kept as nearly uniform as possible. Three to five series of tests were run with each boiler. All tests in each series were of nearly the same initial temperature. Each series contains from 15 to 30 tests which were run with different drafts. Thus each series shows the effect of the velocity of air passing along the heating surface on the rate of heat absorption; the different series of the tests on the same boiler show the effect of the initial temperature; while the tests on different boilers give the influence of the diameter and length of the flues.

The duration of each test was from 30 min. to 2 hours. With high drafts and high temperatures the tests were shorter, because enough water was evaporated in shorter time to make tests as accurate as when running two hours with low drafts and low temperatures.

On all the tests so far done the following temperature readings by the ordinary Fah. scale have been taken:

t_a = Temperature of air entering furnace,
T = Temperature of air entering boiler (initial temp.),
t_f = Temperature of air leaving boiler,
t_s = Temperature of steam,
t_w = Temperature of feed water,

Also the following:

d = Draft of air, entering boiler, and
D = Draft of air, leaving boiler, measured in inches of water.

W = Water condensed in cubic centimeters.
E = Electrical energy in Watt hours consumed during test.

METHOD OF CALCULATION.

The weight of air, M, passing through the boiler per second is obtained from the equation

$$W\ [965.7 + (t_s - t_w)] = 0.2375\ M\ (T - t_f)$$

Hence
$$M = \frac{W\ [965.7 + (t_s - t_w)]}{0.2375\ (T - t_f)}$$

The volume, V, of the air entering the boiler is determined from the relation based on the fundamental properties of permanent gases, as

$$\frac{V}{12.387\ M} = \frac{T + 461}{493}$$

Whence
$$V = \frac{(T + 461) \times 12.387\ M}{493}$$

and the velocity, v, of the air entering the boiler, is

$$v = \frac{V \times 144}{n d^2 \times .7854}$$

where d is the internal diameter, and n the number of flues in the boiler.

If in the calculation above indicated W is reduced to water evaporated per second, then the velocity, v, is in feet per second.

The heat absorbed by the boiler per second is given by the equation

$$H = W\ [965.7 + (t_s - t_w)]$$

where W is expressed in pounds of water evaporated per second.

The true boiler efficiency, E4, is given by the ratio,

$$\frac{\text{Heat absorbed by boiler}}{\text{Heat available for boiler}}$$

and is computed by the equation

$$E_4 = \frac{T - t_f}{T - t_s}$$

The true boiler efficiency was also computed from the heat supplied by the electrical energy. However the efficiency so calculated was less consistent than that calculated as outlined above. This was probably on account of the variation in the heat lost by radiation.

RESULTS OF EXPERIMENTS.

Tables No. I, II, and III give the data and results of all reliable tests made on the small boilers described in the preceding pages. In these tables the figures at the top of the temperature columns indicate the position of the thermometers as shown in Fig. 2.

INTERPRETATION OF CHARTS.

Charts No. 1 to No. 9, were plotted to show graphically the relation between the various factors and the rate of heat absorption. The fact that in some cases the points are somewhat scattered from the smooth curve passed through them may be accounted for by errors in temperature measurements. These errors in the worst cases may amount to 5% of the temperature recorded.

The upper curves of Chart No. 1, show that the heat absorbed by the boiler per second varies almost directly as the calculated velocity of air. Tests having nearly the same initial temperature fall in the same smooth curve which is almost a straight line. With the same initial velocity of air, tests with higher temperatures give higher rate of heat absorption. However, the rate of heat absorption is not a straight line function of the initial temperature as indicated by the constant velocity curves of Chart No. 2. As the initial temperature of the air rises, the rate of heat absorption does not increase in proportion to the temperature, and the constant velocity curves flatten down until probably at very high temperature there is very little or no gain in the heat absorbed by further rise in temperature. This fact indicates that there is another factor influencing the rate of heat absorption, which factor varies inversely

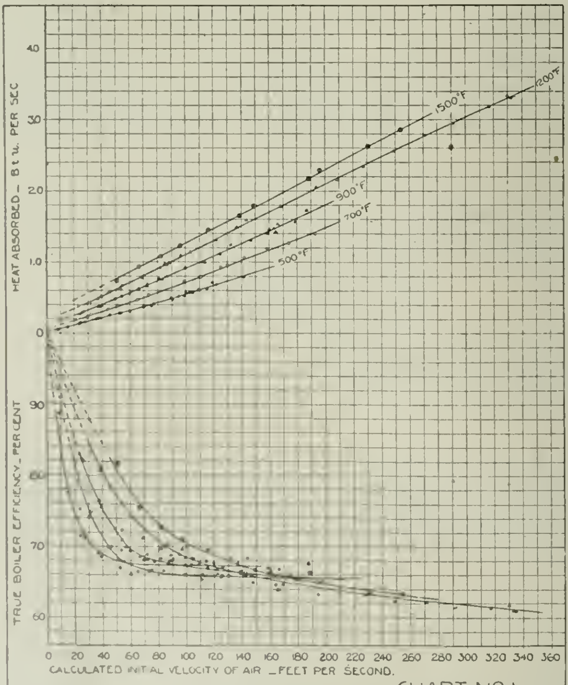

CHART NO. 1
BOILER NO 2

86A	175	0.0	0.5	0.5	1005	990	950	982	302	290	286	[illegible]	62	210	62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
86B	155	0.0	0.5	0.5	980	975	970	975	300	290	287	292	60	210	60	1812	1121	.2970	.00183	39.5	89.26	9.9
88A	180	0.1	1.1	1.0	990	980	970	980	335	326	322	328	71	210	75	2776	1966	.4421	.00286	62.0	84.67	6.6
88B	180	0.1	1.1	1.0	980	990	970	980	347	335	332	338	67	210	65	3160	2147	.4872	.00320	69.3	83.38	6.0
89	120	0.2	2.2	2.0	1015	995	985	998	380	367	365	370	74	210	110	2892	1796	.6453	.00433	95.0	79.70	4.5
89A	120	0.2	2.2	2.0	1000	980	985	988	368	358	356	361	76	210	85	2866	2039	.6815	.00458	99.8	80.59	4.3
90	125	0.4	4.4	4.0	1005	975	985	988	378	373	371	374	74	210	100	4462	2955	.9351	.00641	139.9	78.92	3.1
90A	150	0.4	4.4	4.0	1005	970	970	982	380	371	369	373	71	210	88	5206	3757	1.002	.00693	150.5	78.89	2.9
91A	180	0.8	8.7	7.9	1005	980	975	987	382	357	354	364	80	210	88	8340	6802	1.511	.01022	222.6	80.18	1.9
91	150	0.8	8.8	8.0	1015	970	960	982	389	375	373	379	64	210	84	7178	4904	1.312	.00916	199.0	78.11	2.2

Table No. I.

Data and Results of Tests on Boiler No. 1.

Number of Test	Duration of test, Minutes	Draft Inches water			Temperatures degree F								Air entering furnace	Steam	Feed water	Electrical-energy consumed watt hours	Water condensed c. c.	Heat absorbed B. t. u. per sec.	Air passed thru boiler lb. per sec.	Velocity of air entering boiler ft. per sec.	True boiler Eff. E4	Heating surface per boiler H. P. sq. ft.
		Entering boiler	Leaving boiler	Difference	Air Entering Boiler Thermometers				Air Leaving Boiler Thermometers													
					1	2	3	Av.	1	2	3	Av.										
59	90	0.0	0.3	0.3	506	502	..	504	222	225	..	223	59	209	68	534	152	.0688	.00103	15.0	95.20	42.5
84A	180	0.1	0.6	0.5	499	506	..	502	247	...	..	247	63	209	62	1110	490	.1114	.00184	26.6	87.24	26.3
84	180	0.1	0.6	0.5	494	502	..	498	244	...	..	244	59	209	67	964	502	.1138	.00188	27.2	88.00	25.7
60	42	0.1	0.6	0.5	504	502	..	503	236	240	..	238	66	210	..	272	150	.1454	.00231	33.5	90.40	20.1
62	54	0.1	0.8	0.7	502	505	..	504	251	256	..	253	76	210	..	396	214	.1416	.00238	34.6	85.30	20.7
61	45	0.1	1.1	1.0	498	502	..	500	254	258	..	256	73	210	..	392	210	.1652	.00285	41.2	84.20	17.7
63	42	0.1	1.6	1.5	496	502	..	499	263	267	..	265	66	210	..	456	246	.2073	.00375	54.1	80.70	14.1
71	180	0.2	2.2	2.0	494	503	..	498	261	263	..	262	65	210	68	2362	1063	.2403	.00429	61.9	81.88	12.2
72	120	0.2	2.2	2.0	495	505	..	500	266	268	..	267	69	211	76	1632	724	.2440	.00441	63.8	80.44	12.0
73	120	0.2	2.2	2.0	489	500	..	494	266	269	..	268	74	211	89	1576	751	.2502	.00479	66.7	80.05	11.7
64	39	0.3	3.3	3.0	496	500	..	498	256	261	..	259	73	210	..	632	278	.2720	.00479	69.2	83.04	10.8
74A	120	0.4	4.3	3.9	493	503	..	498	265	268	..	267	75	209	81	2132	925	.3103	.00565	81.6	80.02	9.4
74C	110	0.4	4.3	3.9	491	501	..	496	264	266	..	265	74	209	74	1956	939	.3458	.00631	90.9	80.40	6.7
74B	120	0.4	4.4	4.0	501	495	..	498	264	266	..	265	74	209	73	2208	1068	.3609	.00654	94.4	80.41	8.1
76	120	0.8	8.7	7.9	487	498	..	492	263	264	..	264	75	209	78	2776	1311	.4410	.00812	116.5	80.74	6.6
75A	120	0.9	8.8	7.9	481	495	..	489	260	262	..	261	71	209	76	2524	1319	.4576	.00846	120.9	81.44	6.4
75B	120	0.8	8.9	8.1	485	499	..	492	262	264	..	263	76	209	81	2726	1248	.4310	.00792	113.5	81.00	6.8
65	45	1.3	14.9	13.6	486	504	..	495	259	262	..	262	71	210	78	1440	628	.5630	.01017	146.4	81.60	5.9
77	120	1.7	18.6	16.9	483	503	..	493	260	262	..	261	74	209	80	3920	1775	.5959	.01083	155.5	81.58	4.9
85	180	0.0	0.5	0.5	700	702	..	701	270	...	..	270	62	209	61	1672	854	.1945	.00190	33.3	87.64	15.0
85A	180	0.0	0.5	0.5	700	702	..	701	266	...	..	266	62	209	60	1396	900	.2072	.00201	35.1	88.35	14.1
78A	120	0.1	1.1	1.0	702	702	..	702	289	294	..	292	75	209	86	1618	848	.2832	.00290	50.9	83.22	10.3
79B	80	0.1	1.1	1.0	695	699	..	697	294	297	..	296	73	209	..	940	668	.2957	.00311	54.1	82.22	9.9
80	120	0.2	2.2	2.0	694	704	..	699	308	312	..	310	73	209	94	2162	1290	.4438	.00481	83.9	79.44	6.6
80D	100	0.2	2.2	2.0	690	700	..	695	312	315	..	314	73	210	80	1696	1054	.4375	.00483	84.0	78.64	6.7
80A	120	0.2	2.2	2.0	690	700	..	695	311	314	..	312	76	210	118	2160	1296	.4332	.00480	85.2	78.87	6.8
80B	120	0.2	2.2	2.0	690	700	..	695	312	314	..	313	75	210	114	2144	1306	.4387	.00497	86.8	78.63	6.7
80C	120	0.2	2.2	2.0	691	702	..	695	313	315	..	314	72	210	81	2184	1295	.4472	.00518	90.3	78.79	6.5
81C	60	0.4	4.4	4.0	680	698	..	689	317	319	..	318	72	210	144	1446	722	.4565	.00523	90.6	77.35	6.4
81A	120	0.4	4.4	4.0	687	702	..	695	313	314	..	314	81	209	86	2810	1691	.5646	.00625	108.7	78.38	5.2
81B	120	0.4	4.4	4.0	683	700	..	677	318	321	..	320	76	211	116	2968	1624	.5274	.00625	107.1	76.79	5.5
82	120	0.8	8.7	7.9	684	701	..	693	313	...	..	314	72	210	85	4154	2435	.8138	.00911	156.9	78.52	3.6
82B	120	0.8	8.7	7.9	685	706	..	696	315	...	..	315	72	210	92	4186	2222	.7379	.00817	142.1	78.37	4.0
82A	120	0.8	8.8	8.0	684	707	..	697	315	...	..	315	76	210	100	4158	2262	.7456	.00822	143.3	78.45	3.9
83D	90	0.8	9.1	8.3	685	707	..	696	310	...	..	310	54	210	58	3136	1597	.7293	.00795	138.4	79.53	4.0
83C	120	1.0	11.2	10.2	682	704	..	693	314	...	..	314	60	211	69	4534	2328	.7895	.00876	152.2	78.65	3.7
83B	120	1.2	13.6	12.4	682	702	..	692	315	...	..	315	66	211	86	5068	2644	.8829	.00985	171.0	78.40	3.3
83A	120	1.3	15.1	13.8	682	705	..	694	317	...	..	317	71	211	85	5306	2866	.9579	.01071	186.1	77.94	3.1
86A	175	0.0	0.5	0.5	1005	990	950	982	302	290	286	293	62	210	62	1910	1430	.3346	.00204	44.4	89.23	8.7
86B	155	0.0	0.5	0.5	980	975	970	975	300	290	287	292	60	210	60	1812	1121	.2970	.00183	39.5	89.26	9.9
88A	180	0.1	1.1	1.0	990	980	970	980	335	326	322	328	71	210	75	2776	1966	.4421	.00286	62.0	84.67	6.6
88B	180	0.1	1.1	1.0	980	990	970	980	347	335	332	338	67	210	65	3160	2147	.4872	.00320	69.3	83.38	6.0
89	120	0.2	2.2	2.0	1015	995	985	998	380	367	365	370	74	210	110	2892	1796	.6453	.00433	95.0	79.70	4.5
89A	120	0.2	2.2	2.0	1000	980	985	988	368	358	356	361	76	210	85	2866	2039	.6815	.00458	99.8	80.59	4.3
90	125	0.4	4.4	4.0	1005	975	985	988	378	373	371	374	74	210	100	4462	2955	.9351	.00641	139.9	78.92	3.1
90A	150	0.4	4.4	4.0	1005	970	970	982	380	371	369	373	71	210	88	5206	3757	1.002	.00693	150.5	78.89	2.9
91A	180	0.8	8.7	7.9	1005	980	975	987	382	357	354	364	80	210	88	8340	6802	1.511	.01022	222.6	80.18	1.9
91	150	0.8	8.8	8.0	1015	970	960	982	389	375	373	379	64	210	84	7178	4904	1.312	.00916	199.0	78.11	2.2
92A	180	1.1	14.6	13.5	985	960	950	965	380	359	348	362	88	210	97	10436	7582	1.671	.01167	250.5	79.87	1.8
92B	180	1.2	15.2	14.0	1005	975	965	982	385	362	350	366	83	210	100	10766	8084	1.776	.01213	263.5	79.84	1.7

																			[illegible]	[illegible]	61.00	1.2
												[illegible]	[illegible]	[illegible]	226	98	6698	3757	3.320	.02251	335.0	60.80	1.2
				[illegible]	[illegible]	[illegible]	1240	1253	622	621	608	617	64	226	102	6754	3795	3.341	.02212	330.4	61.93	1.2
306	45	.10	.4	.3	1525	1550	1505	1527	464	452	446	454	84	211	85	1138	832	.742	.00292	50.40	81.58	5.18
305	45	.1	.6	.5	1535	1565	1520	1540	527	512	503	514	82	211	87	1356	1045	.929	.00383	66.50	75.38	4.14
304	45	.2	1.0	.8	1520	1550	1500	1523	584	568	562	571	78	212	84	1782	1265	1.073	.00476	82.2	72.58	3.58
303	50	.3	1.3	1.0	1495	1520	1480	1498	595	587	583	588	74	213	82	2170	1524	1.226	.00568	96.8	70.82	3.14
302	45	.4	1.9	1.5	1530	1555	1510	1532	632	613	609	618	72	213	96	2419	1638	1.445	.00666	115.6	69.30	2.60
307	45	.4	2.3	1.9	1485	1515	1475	1492	656	638	637	644	87	214	86	2606	1845	1.645	.00818	139.0	66.35	2.34
296	45	.6	3.2	2.6	1520	1545	1508	1534	666	650	651	656	72	216	84	3096	2000	1.786	.00857	148.8	66.70	2.15
295	45	.8	4.3	3.5	1540	1555	1518	1538	671	655	653	660	72	216	84	3644	2409	2.156	.01034	188.2	66.41	1.71
297	45	1.0	5.2	4.2	1500	1525	1510	1512	686	668	669	674	74	218	86	3772	2562	2.285	.01148	197.3	64.80	1.68
298	45	1.4	7.5	6.1	1515	1525	1495	1512	703	684	686	691	75	221	88	4382	2940	2.620	.01344	231.0	63.62	1.47

Table II.

Data and Results of Tests on Boiler No. 2.

Number of Test	Duration of test, Minutes	Draft Inches water			Temperatures degree F											Electrical-energy consumed watt hours	Water condensed c. c.	Heat absorbed B. t. u. per sec.	Air passed thru boiler. lb. per sec.	Velocity of air entering boiler ft. per sec.	True boiler Eff. E4	Heating surface per boiler H. P. sq. ft.
		Entering boiler	Leaving boiler	Difference	Air entering Boiler Thermometers				Air leaving Boiler Thermometers				Air entering furnace	Steam	Feed water							
					1	2	3	Av.	1	2	3	Av.										
193	120	0.0	.10	.10	510	497	478	495	247	242	239	243	86	211	86	280	161	.0538	.00090	7.5	88.73	71.5
192	120	0.0	.30	.30	496	476	470	481	277	272	268	272	81	211	82	652	260	.0872	.00176	14.4	77.41	44.1
191	120	0.1	.4	.30	519	496	485	500	287	280	280	282	96	211	96	788	437	.1445	.00279	23.4	75.48	26.6
198	120	0.1	.6	.50	504	484	460	483	291	288	285	288	95	210	97	914	466	.1541	.00333	25.0	71.43	25.0
228	95	0.1	.7	.60	512	488	485	495	295	292	289	292	76	211	78	880	318	.1350	.00280	23.3	71.50	28.5
199	120	0.1	.9	.8	512	484	485	495	304	297	294	298	97	210	98	1180	616	.2034	.00437	36.4	69.01	18.9
200	120	0.1	1.1	1.0	515	485	488	503	304	301	302	293	97	210	98	1344	046	.2133	.00447	37.5	68.60	18.0
227	95	0.2	1.7	1.5	513	488	490	497	301	299	298	297	78	211	80	1386	610	.2590	.00546	45.6	69.95	14.9
201	75	0.2	1.7	1.5	511	480	486	492	306	302	301	303	97	210	97	1062	532	.2813	.00627	52.0	67.02	13.7
194	120	0.3	2.3	2.0	507	484	489	493	303	299	289	297	98	211	98	1980	890	.2939	.00631	52.5	69.51	13.1
202	120	0.5	3.4	2.9	505	476	488	490	304	301	299	305	82	210	86	2268	938	.3136	.00714	59.1	66.07	12.3
203	95	0.7	4.7	4.0	515	480	492	496	308	305	305	306	83	211	85	2394	938	.3960	.00873	75.0	66.67	9.5
204	95	0.8	5.7	4.9	508	478	486	491	303	300	296	300	85	211	87	2200	900	.3794	.00836	69.4	68.21	10.1
205	95	1.0	7.0	6.0	500	469	478	482	302	299	294	298	86	211	88	2356	967	.4073	.00932	76.6	67.90	9.4
206	95	1.1	9.1	8.0	504	475	485	488	304	302	297	301	85	210	90	2754	1150	.4835	.01089	90.1	67.27	8.0
224	95	1.9	12.1	10.2	511	489	493	498	306	304	298	303	77	211	83	3250	1160	.4920	.01059	88.6	68.00	7.8
225	70	2.2	14.0	11.8	508	487	491	495	305	304	298	302	78	211	81	2640	835	.4802	.01048	87.3	67.95	8.0
207	95	2.3	14.2	11.9	510	474	473	486	299	297	291	296	83	211	85	3284	1230	.5194	.01151	95.0	69.09	7.4
226	70	2.6	16.2	13.6	505	482	489	492	303	300	295	300	79	211	81	2894	1003	.5770	.01265	105.1	68.30	6.7
232	70	2.5	16.3	13.8	511	495	503	503	307	308	302	306	80	211	81	2910	960	.5531	.01182	99.3	67.47	7.0
195▲	45	2.9	18.6	15.7	516	483	488	496	308	306	302	305	94	211	94	1932	708	.6256	.01379	115.0	67.02	6.2
195	95	2.9	18.9	16.0	509	503	514	509	312	314	304	310	96	211	96	4190	1632	.6819	.01443	122.0	66.78	5.6
231	70	3.0	19.5	16.5	515	499	503	506	310	309	303	307	81	211	80	3260	1010	.5813	.01230	103.6	67.46	6.6
196	95	3.2	22.2	19.0	501	495	502	499	308	305	299	304	97	211	97	4420	1598	.6617	.01429	119.5	67.71	5.8
218	70	3.5	23.5	20.0	510	487	486	494	299	297	291	296	82	211	93	3268	997	.5673	.01206	99.9	69.96	6.8
230	70	3.5	23.7	20.2	513	494	501	503	308	306	299	306	77	211	82	3554	1057	.6074	.01298	109.4	67.47	6.3
229	65	3.8	26.7	22.9	520	504	510	511	316	315	308	313	74	211	93	3546	1293	.7920	.01684	142.6	66.00	4.9
189	120	.0	.2	.2	694	678	663	678	299	296	291	295	96	210	96	836	557	.1842	.00202	20.1	81.84	20.9
188	120	.0	.3	.3	695	679	668	681	316	303	306	308	95	210	95	1000	585	.1936	.00219	21.7	79.19	19.9
190	120	.1	.4	.3	691	670	660	674	330	328	320	326	95	210	95	1228	795	.2633	.00319	31.5	75.00	14.6
208	95	.1	.6	.5	680	659	636	658	330	326	321	326	84	211	94	1112	566	.2369	.00300	29.3	74.27	16.2
209	95	.1	.9	.8	692	662	650	668	347	349	344	347	86	210	88	1380	810	.330	.00445	43.8	70.09	11.4
210	95	.2	1.2	1.0	694	661	652	669	359	355	353	356	87	210	88	1598	918	.3842	.00517	50.9	68.19	10.0
211	95	.2	1.7	1.5	694	658	652	668	366	363	361	363	87	210	88	1842	1145	.4793	.00662	65.0	66.49	8.0
212	95	.3	2.3	2.3	695	659	655	670	368	365	363	365	85	211	87	2238	1293	.5407	.00746	73.6	66.42	7.1
214	95	.6	4.6	4.0	701	672	670	681	375	371	367	371	77	210	80	3200	1718	.7295	.00992	98.7	65.90	5.3
215	70	.9	6.8	5.9	685	659	658	667	372	369	365	369	80	211	82	2674	1390	.7975	.01127	110.9	65.40	4.8
217	55	1.6	9.5	7.9	698	673	670	680	370	374	369	371	78	211	83	2522	1305	.9540	.01300	129.1	65.90	4.1
216	70	1.5	9.5	8.0	696	676	662	678	374	372	364	370	83	211	83	3174	1610	.9255	.01265	125.5	66.10	4.2
220	70	2.2	14.2	12.0	694	685	670	683	375	372	366	371	88	211	89	3830	1860	1.062	.01433	142.9	66.10	3.6
221	70	2.7	18.6	15.9	700	677	674	684	380	378	378	378	87	212	90	4310	2080	1.186	.01638	163.4	64.63	3.2
222	70	3.6	24.0	20.4	692	669	667	676	377	375	367	373	87	212	90	2187	1265	1.265	.01758	174.2	66.10	3.0
223	70	4.1	28.1	24.0	693	670	668	677	378	377	369	375	86	212	90	3094	2378	1.397	.01880	193.1	64.95	2.8
184	120	0.0	.1	.1	905	885	865	885	325	328	320	324	90	211	91	1372	785	.2621	.00197	23.1	83.20	14.7
177	125	0.1	.3	.2	910	905	885	900	...	330	...	330	92	210	99	1368	878	.2791	.00206	24.4	82.60	13.8
241	70	0.0	.3	.3	970	925	895	930	344	343	329	339	93	211	96	686	505	.2864	.00204	26.6	82.20	13.4
124	110	0.1	.6	.5	980	960	930	957	441	433	431	435	83	277	86	1808	1042	.3728	.00301	37.1	76.78	10.3
123	120	0.1	.6	.5	912	894	863	890	409	397	402	403	87	247	88	1816	1133	.3815	.00380	38.8	75.76	10.1
234	70	0.1	.7	.6	885	885	885	885	405	400	384	396	90	210	90	1288	850	.4845	.00417	48.9	72.62	7.9
235	70	0.1	.8	.7	885	885	885	885	415	411	397	406	91	210	91	1490	908	.5179	.00455	53.4	70.94	7.4
156A	120	0.2	1.0	.8	932	910	871	904	429	424	418	424	90	210	92	2940	1700	.5650	.00496	59.0	69.50	6.8
122	120	0.3	1.3	1.0	930	903	868	900	441	436	432	436	83	242	89	2760	1550	.5205	.00472	56.0	70.52	7.4
236	70	0.2	1.2	1 0	905	895	900	900	435	429	417	427	91	211	91	1622	1093	.6235	.00555	55.5	68.61	6.2
183	95	0.3	1.5	1.2	915	895	860	890	426	424	424	425	91	211	91	2230	1612	.6770	.00613	72.2	68 45	5.7
233	70	0.2	1.7	1.5	895	875	885	885	443	440	426	436	89	211	90	2018	1325	.7560	.00709	83.2	66.60	5.1
185	95	0.3	2.0	1.7	935	920	875	910	426	425	421	424	93	211	94	2592	1673	.7002	.00607	72.5	69.08	5.5
114	100	0.5	2.4	1.9	953	937	924	938	444	438	435	439	84	210	86	3466	1975	.7834	.00661	80.6	69.00	4.9
237	70	0.4	2.4	2.0	885	865	875	875	434	429	416	425	87	211	89	2366	1400	.7999	.00748	87.1	67.79	4.8
250	70	0.6	3.6	3.0	890	906	904	900	434	428	419	427	81	211	118	2814	1680	.9342	.00833	98.7	68.63	4.1
238	70	0.5	3.6	3.1	910	880	895	895	452	447	437	445	93	211	93	2856	1766	1.006	.00942	111.2	66.10	3.8
125	85	0.9	4.7	3.8	924	918	890	911	484	479	478	480	72	277	75	3628	2024	.9820	.00960	114.7	68.00	3.9
251	70	0.8	4.8	4.0	900	910	905	905	444	440	429	438	84	212	90	3184	1940	1.170	.01060	126.2	67.35	3.3
120	110	1.0	5.1	4.1	967	940	900	936	482	478	486	482	88	248	92	5434	3024	1.107	.01027	125.0	65.99	3.5
248	60	1.2	7.0	5.8	895	920	915	910	432	439	427	433	90	212	94	3200	1890	1.252	.01105	132.0	68.40	3.1
240	70	0.9	6.8	5.9	915	875	895	895	460	456	446	454	93	213	96	3714	2310	1.310	.01250	147.6	65 03	2.9
240A	65	1.2	9.2	8.0	865	850	865	860	454	449	438	447	95	214	99	3780	2315	1.410	.01439	165.6	63.90	2.8
249	60	1.5	9.6	8.1	880	890	885	885	439	439	426	435	91	213	100	3654	2117	1.394	.01304	158.0	66.95	2.8
252	60	1.9	11.8	9.9	910	925	910	915	454	448	436	446	85	214	91	4014	2321	1.544	.01386	166.2	66.91	2.5
242	45	1.9	12.0	10.1	910	880	880	890	453	446	435	445	85	214	90	3060	1656	1.469	.01388	163.4	65.88	2.6
244	60	1.8	11.9	10.1	890	900	880	890	440	435	423	432	91	213	92	3904	2220	1.476	.01356	159.7	67.60	2.6
243	45	2.2	13.9	11.7	905	855	865	875	453	446	434	444	89	215	94	3078	1778	1.571	.01534	178.6	65.31	2.5
247	60	2.8	17.9	15.1	910	920	903	911	453	446	433	444	90	216	97	4652	2610	1.728	.01559	186.4	67.75	2.2
261	70	.1	.2	.1	1275	1245	1215	1245	412	411	394	406	83	211	113	1152	916	.5110	.00257	38.1	81.14	7.5
187	120	.1	.2	.1	1226	1182	1142	1183	...	399	...	399	79	210	78	2168	1430	.4825	.00259	37.1	80.70	8.0
257	70	.1	.3	.2	1235	1210	1185	1210	437	432	415	426	82	211	82	1442	1005	.5775	.00310	45.2	78.50	8.6
173	120	.1	.3	.2	1245	1206	1170	1207	...	374	...	374	80	210	82	1804	1292	.4323	.00219	31.9	83.55	8.9
256	70	.1	.6	.5	1225	1215	1205	1215	462	455	437	451	80	211	90	1860	1173	.6690	.00369	53.8	76.02	5.8
161	120	.2	.7	.5	1222	1201	1175	1199	492	482	475	483	80	210	83	3136	1868	.6251	.00368	63.2	72.40	6.2
166	95	.2	.9	.7	1231	1195	1170	1199	499	491	489	493	83	211	84	2424	1888	.7973	.00476	68.8	71.43	4.8
258	70	.3	1.3	1.0	1250	1215	1180	1215	521	514	505	513	83	211	84	2520	1690	.9695	.00582	84.9	69.95	4.0
167	95	.2	1.3	1.1	1236	1196	1168	1200	513	507	506	509	84	211	118	2988	2228	.9138	.00557	80.6	69.80	4.2
182	95	.3	1.6	1.3	1228	1208	1173	1203	515	507	505	509	89	212	91	3310	2303	.9657	.00568	86.5	70.03	4.0
168	95	.3	1.8	1.5	1239	1191	1159	1196	521	516	516	518	85	212	111	3278	2390	.9852	.00612	88.4	68.91	3.9
181	95	.4	2.2	1.8	1244	1205	1160	1203	517	513	507	512	87	212	91	3786	2603	1.091	.00665	96.4	69.72	3.5
259	60	.5	2.4	1.9	1210	1220	1200	1210	554	550	543	549	85	213	117	2792	2033	1.319	.00840	122.3	66.21	2.9
169	95	.4	2.4	2.0	1228	1179	1140	1182	522	518	514	518	83	212	105	3758	2750	1.140	.00723	103.5	68.45	3.4
300	30	.8	4.2	3.4	1228	1240	1210	1226	593	578	578	583	76	215	79	1986	1296	1.746	.01144	168.2	63.64	2.2
260	60	.9	4.7	3.8	1225	1230	1220	1225	577	573	565	572	86	217	126	3980	2783	1.790	.01154	168.6	64.80	2.2
171	95	.7	4.9	4.2	1220	1176	1133	1176	525	521	520	522	86	214	87	5070	3536	1.495	.00963	137.3	67.98	2.6
178	95	.8	5.5	4.7	1240	1198	1140	1193	526	523	517	522	95	214	94	5258	3784	1.585	.00995	143.4	68.55	2.4
289	45	1.2	6.2	5.0	1240	1230	1220	1230	592	592	584	589	67	216	65	3546	2250	2.007	.01318	194.3	63.28	1.9
288	45	1.4	7.8	6.4	1245	1240	1225	1237	595	595	587	592	64	217	88	3936	2422	2.155	.01406	208 2	63.24	1.8
281	60	1.9	10.2	8.3	1225	1240	1205	1223	593	592	581	589	73	218	112	5562	3583	2.339	.01553	228.0	63.09	1.6
282	60	2.3	12.8	10.5	1230	1250	1220	1233	608	606	595	603	73	221	99	6112	3857	2.552	.01688	249.1	62.30	1.5
283	60	2.6	14.8	12.2	1255	1260	1250	1255	617	616	604	612	74	221	98	6662	4181	2.770	.01813	271.2	62.20	1.4
284	60	2.9	17.2	14.3	1235	1255	1250	1247	623	616	608	616	74	222	105	7170	4470	2.940	.01962	292.0	61.57	1.3
285	45	3.3	19.8	16.5	1235	1238	1230	1234	621	622	600	614	72	224	105	5770	3500	3.166	.02150	317.6	61.39	1.2
286	45	3.8	23.4	19.6	1245	1240	1225	1237	627	625	612	621	71	227	104	6302	3737	3.288	.02248	333 0	61.00	1.2
293	45	4.3	27.5	23.2	1255	1240	1245	1247	635	...	616	626	72	226	98	6698	3757	3.320	.02251	335.0	60.80	1.2
287	45	4.4	28.0	23.6	1265	1255	1240	1253	622	621	608	617	64	226	102	6754	3795	3.341	.02212	330.4	61.93	1.2
306	45	.10	.4	.3	1525	1550	1505	1527	464	452	446	454	84	211	85	1138	832	.742	.00292	50.40	81.58	5.18
305	45	.1	.6	.5	1535	1565	1520	1540	527	512	503	514	82	211	87	1356	1045	.929	.00383	66.50	75.38	4.14
304	45	.2	1.0	.8	1520	1550	1500	1523	584	568	562	571	78	212	84	1782	1265	1.073	.00476	82.2	72.58	3.58
303	50	.3	1.3	1.0	1495	1520	1480	1498	595	587	583	588	74	213	82	2170	1524	1.226	.00568	96.8	70.82	3.14
302	45	.4	1.9	1.5	1530	1555	1510	1532	632	613	609	618	72	213	96	2419	1638	1.445	.00666	115.6	69.30	2.60
307	45	.4	2.3	1.9	1485	1515	1475	1492	656	638	637	644	87	214	86	2606	1845	1.645	.00818	139.0	66.35	2.34
296	45	.6	3.2	2.6	1520	1545	1508	1534	666	650	651	656	72	216	84	3096	2000	1.786	.00857	148.8	66.70	2.15
295	45	.8	4.3	3.5	1540	1555	1518	1538	671	655	653	660	72	216	84	3644	2409	2.156	.01034	188.2	66.41	1.71
297	45	1.0	5.2	4.2	1500	1525	1510	1512	686	668	669	674	74	218	86	3772	2562	2.285	.01148	197.3	64.80	1.68
298	45	1.4	7.5	6.1	1515	1525	1495	1512	703	684	686	691	75	221	88	4382	2940	2.620	.01344	231.0	63.62	1.47
299	45	1 6	8.6	7.0	1505	1520	1490	1505	708	689	691	696	75	223	91	4762	3213	2.858	.01487	254.6	63.13	1.35

gas. Points
upper curves

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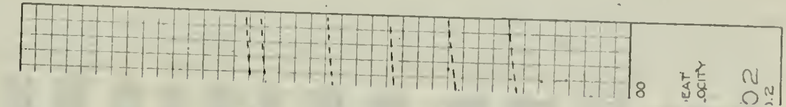


341	45	0.1	1.3	1.2	[illegible]	[illegible]																
340	35	0.2	2.5	2.3	1555	1510	1510	1525	405	[illegible]	[illegible]	[illegible]										
233	45	0.1	2.7	2.6	1580	1520	1525	1542	394	387	386	389	76	211	90	1600	[illegible]	[illegible]	[illegible]			
332	45	0.25	4.2	3.95	1510	1485	1480	1492	409	402	402	404	78	212	103	1930	1614	1.412	.00547	161.0	85.1	4.04
339	35	0.3	5.3	5.0	1515	1475	1465	1485	396	388	391	392	82	213	107	1666	1274	1.430	.00551	161.5	85.95	3.98
334	45	0.3	6.2	5.9	1555	1525	1520	1533	396	387	390	391	80	214	128	2340	2020	1.730	.00638	191.5	86.6	3.29
335	35	0.5	9.6	9.1	1535	1505	1500	1513	372	365	365	367	80	216	107	2112	1978	2.223	.00817	242.8	88.35	2.59
336	35	0.6	12.6	12.0	1550	1520	1510	1527	375	368	370	371	82	217	106	2368	2245	2.525	.0092	275.4	88.2	2.26
337	30	0.8	17.0	16.2	1515	1490	1480	1495	375	368	365	369	83	219	106	2278	2204	2.894	.01082	318.8	88.2	2.38
338	40	1.0	21.1	20.1	1525	1490	1485	1500	380	374	369	374	84	222	105	3296	3126	3.082	.01153	340.5	88.15	1.85

No water fed into the boiler during test.

Table III.

Data and Results of Tests on Boiler No. 3.

Number of Test	Duration of test, Minutes	Draft Inches water			Temperatures degree F											Electrical-energy consumed watt hours	Water condensed c. c.	Heat absorbed B. t u. per sec.	Air passed thru boiler lb. per sec.	Velocity of air entering boiler ft. per sec.	True boiler Eff E4	Heating surface per boiler H. P. sq. ft.
		Entering boiler	Leaving boiler	Difference	Air entering Boiler Thermometers				Air leaving Boiler Thermometers				Air entering furnace	Steam	Feed water							
					1	2	3	Av.	1	2	3	Av.										
276	125	0.0	.5	.5	688	683	675	682	232	...	230	231	71	210	72	780	413	.1342	.00125	21.0	95.50	42.4
265	120	0.1	1.1	1.0	683	683	676	681	262	256	255	258	74	212	78	1182	690	.2322	.00232	26.5	88.40	24.5
266	95	0.1	1.6	1.5	681	683	669	678	280	273	273	275	74	212	78	1134	720	.3060	.00320	54.8	86.45	18.6
277	120	0.2	2.2	2.0	681	681	681	681	286	281	282	283	91	211	93	1628	1130	.3749	.00397	68.2	84.68	15.2
267	95	0 1	2.2	2.1	683	687	682	684	291	285	285	287	79	212	83	1322	890	.3768	.00400	69.2	84.10	15.1
268	70	0.3	3.2	2.9	687	691	687	688	292	288	287	289	84	212	90	1212	852	.4862	.00514	88.8	83.80	11.7
278	70	0.2	3.3	3.1	682	684	684	683	290	285	285	283	93	211	100	1092	860	.4860	.00512	88.1	84.74	11.7
264	70	0.3	4.2	3.9	683	697	680	687	283	278	277	279	80	212	84	1368	947	.5432	.00501	97.0	85.90	10.5
279	70	0.2	4.2	4.0	678	675	679	677	281	277	277	278	92	211	100	1280	1020	.6040	.00637	109.2	85.62	9.4
269	60	0.4	5.4	5.0	684	688	684	685	280	276	276	277	84	216	91	1258	970	.6448	.00665	114.9	87.00	8.8
280	70	0.3	6.2	5.9	676	677	679	677	273	271	270	271	91	211	115	1520	1184	.6594	.00684	117.2	87.13	8.6
263	70	0.4	6.7	6.3	683	688	684	685	276	272	271	273	84	215	84	1654	1208	.6930	.00708	122.2	87.62	8.2
262	70	0.5	8.3	7.9	681	696	683	687	276	271	270	272	81	216	88	1846	1358	.7762	.00788	130.2	88.10	7.8
270	60	0.6	10.5	9.9	684	685	685	685	272	267	266	268	83	212	94	1716	1423	.9430	.00953	164.6	88.15	6.0
271	60	0.7	12.6	11.9	685	687	687	686	277	269	257	268	86	212	88	1836	1590	1.062	.01070	184.7	88.20	5.4
272	60	0.8	14.6	13.8	684	686	687	686	279	270	279	273	86	212	87	1978	1740	1.151	.01174	205.4	87.18	5.0
273	60	0 9	16.9	16.0	681	682	684	682	277	271	270	273	90	212	104	2096	1878	1.234	.01271	218.7	87.00	4.6
274	60	1.0	19.1	18.1	684	686	687	686	279	273	271	274	90	212	104	2214	1970	1.294	.01322	228.4	86.90	4.4
275	55	1 1	20.8	19.7	683	685	686	683	275	274	280	275	90	218	97	2108	1970	1.421	.01407	252.7	86.80	4.0
308	100	0.0	1.0	1.0	885	885	885	885	269	263	262	265	80	211	80	1060	810	.3263	.00222	45.0	91.95	17.4
309	70	0.1	2.1	2.0	885	880	880	882	313	307	307	309	82	211	80	1188	806	.4639	.00341	67.4	85.41	15 6
310	55	0.2	4.2	4.0	870	865	865	867	315	309	306	310	82	211	82	1532	1066	.7800	.00590	117.9	84.90	7.3
311	37	0.3	6.3	6.0	890	875	880	882	299	293	294	295	84	212	131	1112	965	1.002	.00719	145.4	87.60	5 7
326	95	.0	0.5	0.5	910	870	875	885	234	...	230	232	77	212	•	808	555	2070	.00133	27.05	97.05	27.51
318	70	0.2	3.2	3.0	905	870	875	883	316	310	310	312	77	212	102	1408	1140	.6412	.00473	95.6	85.1	8.88
317	45	0.3	5.2	4.9	905	870	880	885	291	289	289	290	79	211	81	1190	938	.8400	.00595	120.5	88.3	6.78
312	45	0.4	7.4	7.0	900	870	875	882	287	283	282	284	77	213	98	1428	1165	1.026	.00722	146.0	89.4	5.55
313	45	0.5	9.7	9.2	890	870	875	878	292	286	284	287	78	212	87	1620	1305	1 162	.00824	166.1	89.2	4.90
314	45	0.7	12.7	12.0	890	870	875	878	292	289	288	290	79	213	83	1820	1467	1 310	.00938	189.2	88.4	4 35
315	50	0.9	16.2	15.3	890	870	875	878	298	292	290	293	78	213	82	2260	1878	1.510	.01087	219.1	88.00	3.77
316	45	1.0	19.1	18.1	880	860	875	872	300	293	290	294	80	213	84	2200	1777	1.586	.01156	232 0	87.7	3.59
331	50	0.8	19.9	19.1	920	900	905	908	304	299	297	300	80	214	120	2406	2200	1.710	.01184	244.0	87.6	3.33
329	45	0.8	22.1	21.3	920	905	910	912	307	302	300	304	80	214	81	....	2066	1.850	.0128	265.2	87.1	3.08
325	55	0	0.85	0.85	1245	1170	1185	1200	271	269	270	268	76	211	•	748	717	0.462	.00209	52.2	94.25	12.32
327	60	0.1	1.3	1.2	1260	1210	1225	1232	312	305	304	307	79	212	78	1196	904	.6082	.00277	73.82	90.70	9.36
324	55	0.1	2.2	2.1	1245	1190	1185	1207	355	352	352	353	79	211	86	1442	1133	.8260	.00407	102 8	85.72	6.89
228	45	0.13	3.16	3 03	1240	1215	1215	1223	374	368	367	370	80	212	77	1378	1092	.981	.00485	122.8	84.4	5.81
323	45	0.2	4.14	3.94	1225	1180	1180	1195	354	352	353	353	80	212	95	1426	1250	1 104	.00552	137.6	85 6	5.16
319	45	0.4	5.7	5.3	1260	1200	1215	1225	327	324	323	325	71	213	108	....	1568	1.367	.00639	162.4	88.92	4.17
320	45	0.5	8.3	7.8	1230	1180	1185	1198	324	320	319	321	74	213	89	2030	1735	1.542	.00741	185 0	89.05	3.69
321	45	0.7	12.7	12.0	1230	1185	1195	1203	331	326	327	328	78	215	85	2486	2133	1.905	.00917	229.8	88.58	2.99
322	45	0.9	18.0	17.1	1240	1200	1210	1217	340	335	334	336	80	217	103	2926	2672	2 342	.0112	283.0	88.1	2.43
330	45	0.9	21.4	20.5	1240	1210	1210	1220	345	338	336	340	81	218	106	3176	2883	2.525	.01209	306.2	87.88	2.26
342	55	0	0.5	0 5	1565	1460	1470	1498	246	244	245	245	80	211	•	1000	625	.4025	.00135	39.9	97.35	14.15
341	45	0.1	1.3	1.2	1555	1480	1490	1508	325	320	320	322	80	211	84	1000	842	.751	.00267	79.0	91 45	7.58
340	35	0.2	2.5	2.3	1555	1510	1510	1525	405	396	399	400	82	212	92	1304	1018	1.158	.00434	129 8	85.6	4.92
233	45	0.1	2.7	2.6	1580	1520	1525	1542	394	387	386	389	76	211	90	1600	1200	1.065	.0039	117.3	86.6	5.34
332	45	0.25	4.2	3.95	1510	1485	1480	1492	409	402	402	404	78	212	103	1930	1614	1.412	.00547	161.0	85.1	4.04
339	35	0.3	5.3	5.0	1515	1475	1465	1485	396	388	391	392	82	213	107	1666	1274	1.430	.00551	161.5	85.95	3.98
334	45	0.3	6.2	5.9	1555	1525	1520	1533	396	387	390	391	80	214	128	2340	2020	1 730	.00638	191 5	86.6	3.20
335	35	0.5	9.6	9.1	1535	1505	1500	1513	372	365	365	367	80	216	107	2112	1978	2.223	.00817	242.8	88.35	2.59
336	35	0.6	12.6	12.0	1550	1520	1510	1527	375	368	370	371	82	217	106	2368	2245	2 525	.0092	275.4	88.2	2.26
337	30	0.8	17.0	16.2	1515	1490	1480	1495	375	368	365	369	83	219	106	2278	2204	2.894	.01082	318.8	88.2	2.38
338	40	1.0	21.1	20.1	1525	1490	1485	1500	380	374	369	374	84	222	105	3296	3126	3 082	.01153	340 5	88.15	1 85

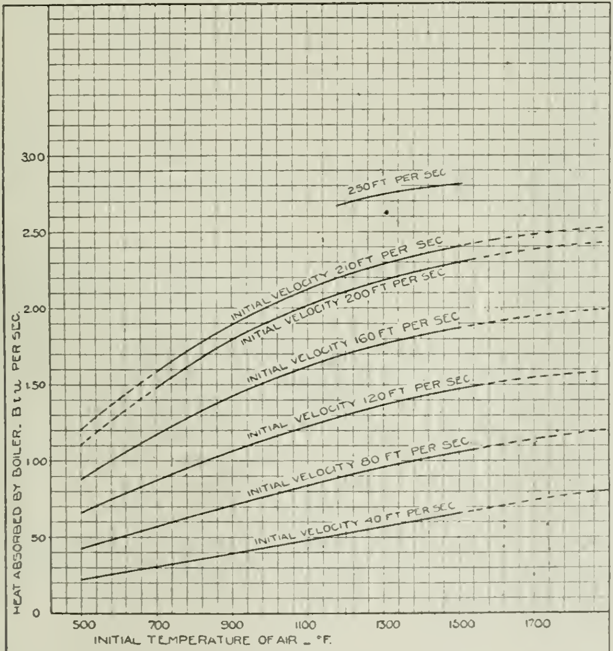
No water fed into the boiler during test.

as the temperature. This factor is the density of the gas. Points for the curves of Chart No. 2, were obtained from the upper curves of Chart No. 1.

The lower curves of Chart No. 1, show that as the initial velocity of air increases, the true boiler efficiency drops at first very rapidly, but, after a certain velocity is reached it becomes nearly constant with the low initial temperatures, and varies but little with higher initial temperatures.

The velocity at which for any initial temperature the true boiler efficiency curve becomes nearly horizontal may be called the *critical velocity.* As shown by the curves, the critical velocity varies with the initial temperature of the air; the higher the initial temperature the higher the critical velocity.

With higher initial temperature the critical velocity is not so well defined as it is with initial temperatures of 500 and 700 deg. F. For very high initial temperatures such as sometimes used in boiler practice (2500 to 3000 deg. F.) the knee probably extends over a considerable range of velocity, so that it is possible that in such a case the boiler never works on the horizontal portion of the curve.



CURVES SHOWING THE RELATION BETWEEN THE RATE OF HEAT ABSORPTION AND INITIAL TEMPERATURE OF AIR WHEN VELOCITY REMAINS CONSTANT

CHART NO 2
BOILER NO. 2

It will be shown later that the critical velocity also varies with the diameter of the tubes.

While with low initial temperatures the portion of the true boiler efficiency curve beyond the critical velocity point is almost perfectly horizontal, with high initial temperatures there seems to be a constant drop even beyond this point. This drop in the efficiency, can be accounted for by the increased rate of heat absorption. It has been explained before, that with the same conditions of the heating plate the quantity of heat transmitted through the plate in a unit of time depends upon the temprature difference of the dry and wet surface or the factor (t_1-t) in equation (2). Since the only way to increase this factor is to increase t, the temperature of the dry surface which does the cooling of the moving gases, the latter will leave the heating surface of the boiler at a proportionately higher temperature than in the case of lower rate of heat absorption.

Chart No. 3, was plotted as a check on the calculated velocity used in Chart No. 1. With constant initial temperature the weight of air passing through the flues must have some constant relation to the difference of pressures at the two ends of the boiler flues. Chart No. 3, shows that such a relation does exist. The curves have a shape similar to a parabola of the equation $y^2 = kx$. With constant initial temperature the initial velocity varies directly as the weight of air passing through the flues, and therefore the same relation exists between the initial velocity and the difference of drafts as that shown in the chart to exist between the weight of air and the difference of drafts. The weight of air passing through the flues varies also with the initial temperature although not in a direct proportion.

Chart No. 4. shows the effect of draft on the true boiler efficiency. The shape of the curves on this chart are somewhat similar to that of the lower curves of Chart No. 1. The true boiler efficiency drops at first very rapidly when the difference of drafts increases, but when the latter reaches about two inches of water the efficiency remains nearly constant. The gradual constant drop in the efficiency curves of the higher initial temperatures beyond the two inch difference of drafts, may be acounted for by rapidly increasing capacity.

It may be questioned why at the left hand side the curves were prolonged to a point of 100 per cent true boiler efficiency when the difference of draft or the velocity is zero. This must necessarily be so because with no velocity the air would remain in the boiler an infinite length of time and its temperature would finally be reduced to the temperature of the steam in the boiler, making the true boiler efficiency equal to 100 per cent.

Chart No. 5, is similar to chart No. 1. It contains results of tests made on boiler No. 1. The last three points on the 900 deg. F. series on the lower curve are very likely too high due perhaps to error in temperature measurement. Both curves show the same features as the curves of chart No. 1. The lower curves of chart

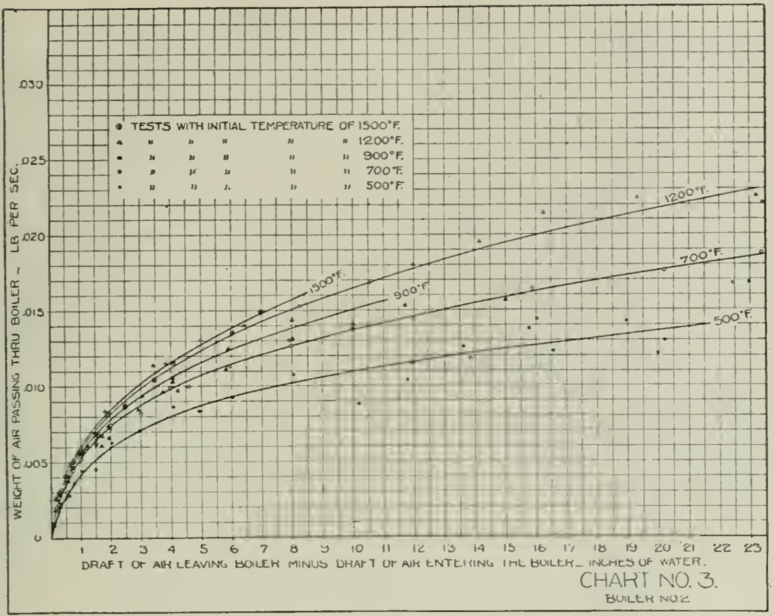


CHART NO. 3.
BOILER NO. 2

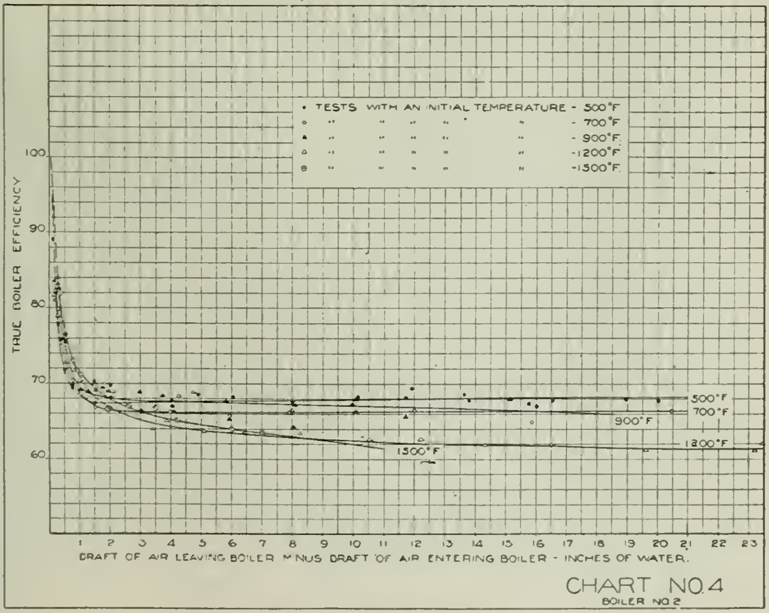


CHART NO. 4
BOILER NO. 2

No. 5, show that with the same initial temperature, the critical velocity is higher for the smaller flues of boiler No. 1, than it is for flues of boiler No. 2. This fact would indicate that with flues of large diameter such as used in locomotive and marine boilers the critical velocity would be very low, so that these boilers, even when using high initial temperatures would be working beyond the critical velocity of their flues, thus showing only small variation in the true boiler efficiency for great range in boiler capacity.

As an illustration of rather a small variation in true boiler efficiency for a considerable range in capacity two sets of tests made on Boiler No. 2, are here given. Taking the initial temperature of 1200 deg. F. and the initial velocity of 85 ft. per sec., the true boiler efficiency is 70 per cent, and the rate of heat absorption about 0.96 B. t. u. per sec. Then taking the same initial temperature but an initial velocity of 335 ft. per sec. the true boiler efficiency is about 61.2 per cent, and the rate of heat absorption 3.35 B. t. u. per second. In the second case, the capacity has been increased 3.48 times, while the efficiency dropped only 8.8 per cent or 12.6 per cent of itself.

Chart No. 6, shows the same features for tests run on boiler No. 1, as charts No. 3 and No. 4, show for tests run on boiler No. 2,

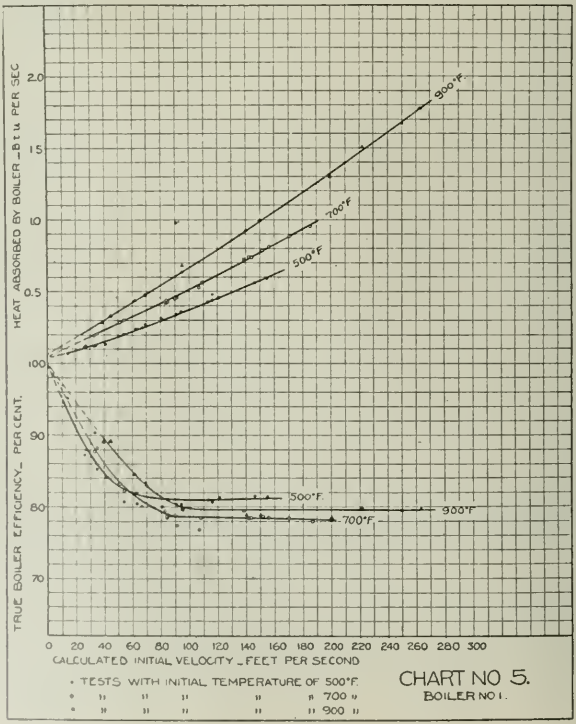


CHART NO 5.
BOILER NO 1.

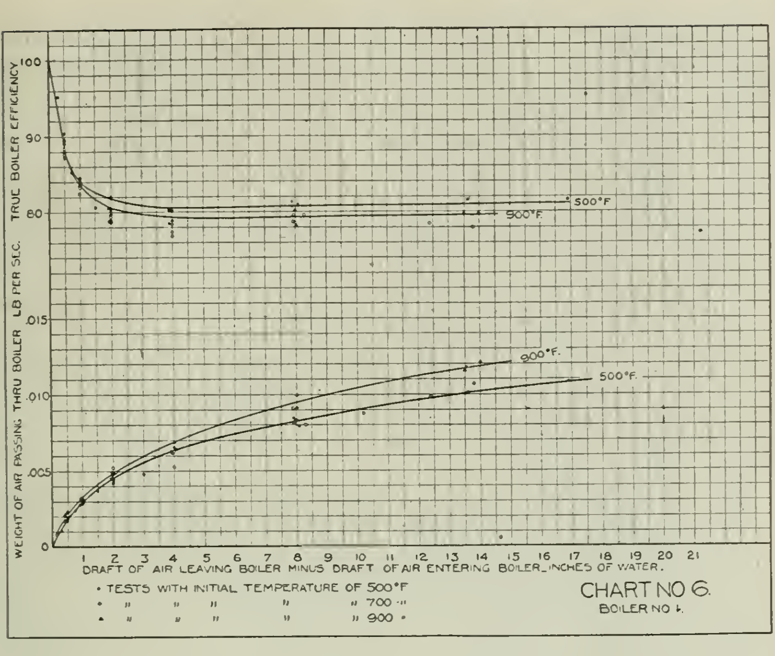


CHART NO 6.
BOILER NO 1.

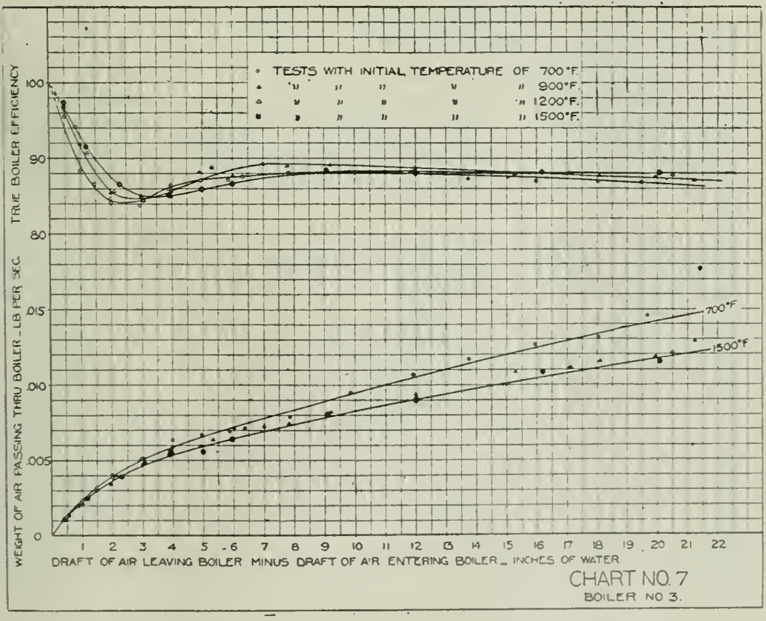


CHART NO. 7
BOILER NO 3.

Comparing the lower curves of chart No. 6, with the curves of chart No. 3, it will be noticed that on account of the flues being larger less draft is required for boiler No. 2, than for boiler No. 1, to pull through its flues the same weight of air at the same initial temperature. Thus taking the initial temperature of 900 deg. F., a difference of drafts of 2 inches of water, is required to pull through the flues of Boiler No. 1, 0.005 lb. of air per second, while only ¾ inch difference of drafts is required to pull the same amount through the flues of boiler No. 2. On the other hand small flues have the advantage of being more efficient. As indicated by Charts No. 1, 4, 5 and 6 the true boiler efficiency of boiler No. 1, is on the average 14 per cent higher than that of boiler No. 2.

Charts No. 7, and No. 8, give plotted results of tests made on boiler No. 3, which had the same size of flues as boiler No. 1, but its length was double that of No. 1. Tests on boiler No. 3. were intended to show the effect of the length of the flues upon the true boiler efficiency.

The two charts No. 7 and No. 8, show that by doubling the length, of flues the efficiency was raised only about 8 per cent.

The upper curve of Chart No. 7, shows one very peculiar feature; as the difference of drafts increase the true boiler efficiency at first drops rather rapidly and then rises again two or three per cent remaining nearly constant for a considerable range of the difference of drafts. As the depression in the curve was difficult to explain, the thermometers were taken out of the apparatus and very carefully put in again to the right depth and check tests were run. These check tests however came very close to the tests run before. On examining closely the upper curves of chart No. 6, it will be noticed that there is a decided tendency for a dip in the same portion of the curves, although at the time the tests were made and plotted, this dip was ascribed to a mere incident. No explanation can, at the present state of the work, be offered for this depression in the efficiency curve.

On comparing the lower curve of charts No. 6, and No. 7, it will be noticed that a given difference of drafts will pull through both boilers nearly the same amount of air. This would seem to indicate that most of the resistance is at the entrance into the flues and very little of it in the tubes themselves, so that an increase in the length of the flues increases the total resistances very little.

Chart No. 9, shows the influence of length and diameter of flues on the true boiler efficiency. The chart gives the final temperatures of the three boilers when the initial temperature is 900 deg. F. and the same weight of air (0.007 lb.) passes through each boiler per second. The curves indicating the drop of the temperature with the length of the flues are asymptotic to the horizontal line of the steam temperature. The chart shows that although the flues of the larger diameter have more heating surface than the flues of the smaller diameter, they are much less efficient.

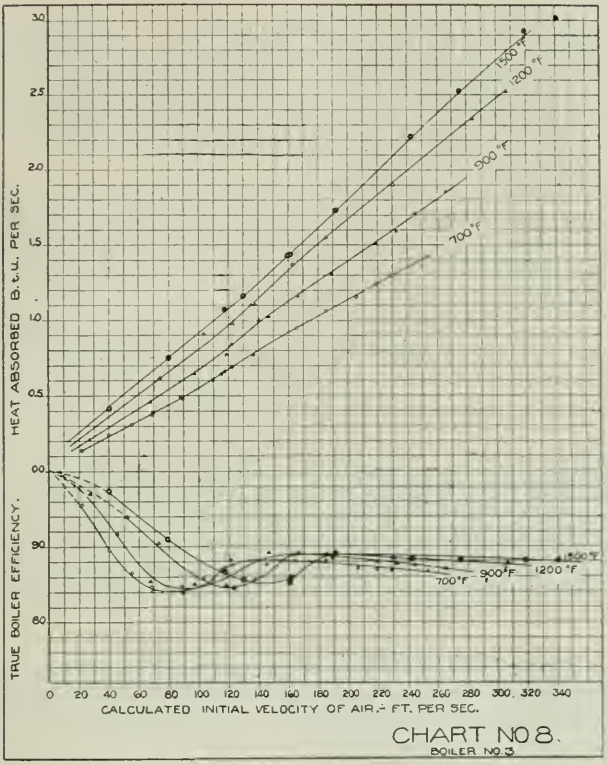


CHART NO 8.
BOILER NO 3

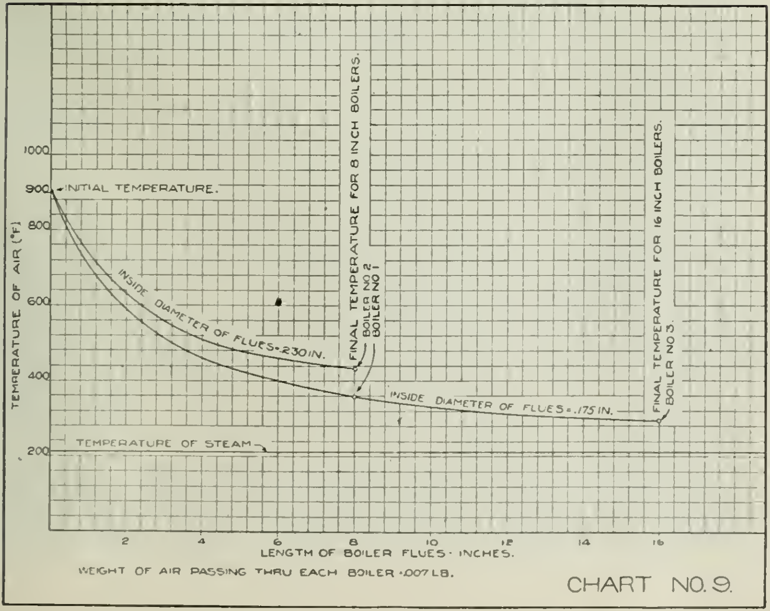


CHART NO. 9.

By doubling the length of flues of Boiler No. 1, only about 8 per cent was gained in the true boiler efficiency as shown by the final temperature of boiler No. 3, it is evident that it does not pay to increase the length of the flues beyond a certain limit.

The deductions drawn from these experiments may be expressed by the following brief statements.

(A) Beyond the points of the critical velocity the rate of heat absorption by convection by the heating plate of boiler flues is nearly a straight line function of the velocity of the gas.

(B) The deviation from the straight line function becomes larger with the rise of the initial temperature.

(C) The critical velocity rises with the initial temperature of the gases. and drops when the diameter of the flues increases.

(D) The rate of heat absorption increases when the initial temperature rises; it also seems to vary directly with the density of the gas.

(E) Increasing the diameter of flues decreases their efficiency as heat absorbers; increasing the length of flues beyond a certain length increases their efficiency very little.

(F) Most of the resistance to the passage of air through the flues is at the entrance into the tubes, the length of the flues increases the resistance but little.

THEORETICAL CONSIDERATIONS.

It may be well to give here extracts from the work done along this line by Prof. Osborne Reynolds and Prof. John Perry of England, and compare the deductions of their study with experimental results presented in this paper.

As far as the authors of this paper know, Prof. Osborne Reynolds was the first to approach the problem of heat impartation to the heating plate by convection in a rational way. As far back as 1874 he read a paper entitled "On the Extent and Action of the Heating Surface for Steam Boilers," before the Literary and Philosophical Society of Manchester, England, in which paper he advanced a theory which appears sound and very close to the truth.

The following is an extract from his paper:

> "The heat carried off by air or any fluid from a surface, apart from the effect of radiation, is proportional to the internal diffusion of the fluid at and near the surface, i. e., is proportional to the rate at which particles or molecules pass backwards and forwards from the surface to any given depth within the fluid; thus, if A B be the surface and a b an ideal line in the fluid parallel to A B, then the heat carried off from the surface in a given time will be proportional to the number of molecules which in that time pass from a b to A B—that is for a given difference of temperature between the fluid and the surface. This assumption is based on the molecular theory of fluids.
>
> Now the rate of this diffusion has been shown from various considerations to depend on two things:
>
> 1. The natural internal diffusion of the fluid when at rest.
> 2. The eddies caused by visible motion which mixes the fluid up and continually brings fresh particles into contact with the surface.
>
> The first of these causes is independent of the velocity of the fluid, if it

be a gas is independent of its density, so that it may be said to depend only on the nature of the fluid.

The second cause, the effect of eddies, arises entirely from the motion of the fluid, and is proportional both to the density of the fluid, if gas, and the velocity with which it flows past the surface.

The combined effect of these two causes may be expressed in a formula as follows:

$$(3)\quad H = At + Bwvt,$$

where t is the difference of temperature between the surface and the fluid, w is the density of the fluid, v its velocity, and A and B constants, depending on the nature of the fluid, H being the heat transmitted per unit of the surface in a unit of time.

If therefore, a fluid were forced along a fixed length of pipe which was maintained at a uniform temperature greater or less than the initial temperature of the gas, we should expect the following results:

1. Starting with a velocity zero, the gas would then acquire the same temperature as the tube.

2. As the velocity increased the temperature at which the gas would emerge would gradually diminish, rapidly at first but in a decreasing ratio until it would become sensibly constant and independent of the velocity. The velocity, after which the temperature of the emerging gas would be sensibly constant, can only be found for each particular gas by experiment; but it would seem reasonable to suppose that it would be the same as that at which the resistance offered by friction to the motion of the fluid would be sensibly proportional to the square of the velocity. It having been found both theoretically and by experiment that this resistance is connected with the diffusion of the gas by a formula:

$$(4)\quad R = A'v + B'wv^2$$

and various considerations lead to the supposition that A and B in (3) are proportional to A′ and B′ in (4). The value of v which this gives is very small, and hence it follows that for considerable velocities the gas should emerge from the tube at a nearly constant temperature whatever may be its velocity.

This, as I am about to point out, is in accordance with what has been observed in tubular boilers as well as in more definite experiments.

In the locomotive, the length of the boiler is limited by the length of tube necessary to cool the air from the fire down to a certain temperature, say 500 deg. F.

Now there does not seem to be any general rule in practice for determining this length, the length varying from 16 ft. to as little as 6 ft., but whatever the proportions may be, each engine furnishes a means of comparing the efficiency of the tubes for high and low velocities of the air through them. It has been a matter of surprise how completely the steam producing power of a boiler appears to rise with the strength of blast or the work required from it, and as the boilers are as economical when working with a high blast as with low, the air going up the chimney cannot have a much higher temperature in the one case than in the other. That it should be somewhat higher is strictly in accordance with the theory as stated above.

It must, however, be noticed that the foregoing conclusion is based on the assumption that the surface of the tube is kept at the same constant temperature, a condition which it is easy to see can hardly be fulfilled in practice."

* * * * * * * * * * * * *

In his book on "Steam Engines and Gas and Oil Engines," Prof. John Perry takes the principles developed by Prof. Osborne Reynolds and works out the following rough theory:

"When fluid is in motion filling a pipe, we know that there is a thin film or layer of fluid entangled among the molecules of the solid surface which is at rest, that is, it has no average velocity relatively to the solid. Let us consider how heat gets into this film from the moving fluid. It is difficult to say whether one ought or ought not to take entrance of heat to this layer of motionless fluid as *entrance*, to the metal itself. There is equalization of the momentum, and there may be equalization of the temperature.

Now suppose *n* molecules per second to enter this layer and the same number to leave it; each of them enters with an average kinetic energy proportional to T the average temperature (absolute) in the pipe, and leaves with t_1 the temperature of the layer, and an average momentum in the axial direction proportional to v if v is the average axial velocity in the pipe.

There is a want of exactness in my definition of these averages, which is, I think, the only weakness in this investigation. Now axially directed momentum gives to the layer per second is what we mean by force of friction F.

So that per unit area,

$$F \propto n\,v. \qquad \text{(I)}$$

and the heat H or kinetic energy per second per unit area

$$H \propto n\,(T - t_1) \qquad \text{(II)}$$

Hence

$$H \propto F\,(T - t_1) \div v \qquad \text{(III)}$$

Of course, when v is o we cannot use (I) in (II) to find (III), but we shall only use our equations in cases where v has some value.

In the standard books on friction of fluids in pipes, the law is given

$$F \propto w\,v^2 \qquad \text{(IV)}$$

where w is the weight of the fluid per unit volume, and v is the average axial velocity in the channel. I am informed by Prof. O. Reynolds that the results of his 1883 paper in the *"Philosophical Transactions"* are applicable to gases, and taking his index there as 2 we have the same formula as (IV); (III) and (IV) give us

$$(5) \quad H \qquad c'\,w\,v\,(T - t_1)$$

where c′ is a constant."

Perry's equation (5) is the same as Osborne Reynold's equation (3), if the first term on the right side of the equation is made to equal zero. It is therefore more correctly applicable only to cases where the motion of the gas exceeds the critical velocity.

Equation (5) gives the amount of heat transmitted per second per elementary area of heating surface of the flues. If the amounts of heat transmitted by every elementary area are added, the heat transmitted by the entire heating surface of the flues per second can be obtained. This can be done in the following way:

Take $(T - t_1) = \Theta$, T being the absolute temperature of the gases at the distance *x* from the furnace end of a flue of total length *l* and diameter D, and t_1 being the temperature of the dry surface. Let M lb. of gases flow through the flue per second, and let the specific heat of the gases at constant pressure be a constant, Sp.

$$(6) \quad \text{Then } w = \frac{c''}{T}$$

$$(7) \quad \text{and } v = \frac{c'''\,MT}{D^2}$$

where c″ and c‴ are same constants.

Equations (6) and (7) are derived from the laws that (a) the density of a gas varies inversely as its absolute temperature, and (b) the velocity varies directly as the weight of the gas which passes through the flue in a second, directly as its absolute temperature (since volume varies directly with the absolute temperature) and inversely as the square of the diameter of the flue. Substituting the values of w and v from equation (6) and (7) in equation (5), the latter becomes

$$H = \frac{C\,v\,\Theta}{T} = \frac{C'M\Theta}{D^2}$$

Hence in a short length dx of the boiler flue the heat transmitted to the boiler is

$$-\,Sp\,M\,d\,\Theta = \frac{C'\,M\,\Theta}{D^2} \times D\pi\,dx = \frac{C''\,M\,\Theta\,dx}{D},$$

$$\text{or,}\quad \frac{d\,\Theta}{\Theta} = -\,\frac{c\,dx}{D},$$

Integrating the above equation it becomes

$$\log\Theta = -\,\frac{c\,x}{D} + K$$

$$\text{When } x = O,\quad K = \log\Theta_0$$

$$\text{When } x = l\quad \log\Theta_l = -\,\frac{cl}{D} + \log\Theta_0$$

$$\text{and}\quad \frac{\Theta_l}{\Theta_0} = e^{-\frac{cl}{D}},$$

Therefore,

$$(8)\quad \Theta_l = \Theta_0 e^{-\frac{cl}{D}}$$

The heat absorbed by the whole flue of the boiler per second is,

$$(9)\quad H = Sp\,M\left(\Theta_0 - \Theta_0\,e^{-\frac{cl}{D}}\right) = Sp\,\Theta_0\left(1 - e^{-\frac{cl}{D}}\right)$$

and the true efficiency of the flue is

$$(10)\quad E = \frac{SpM\ \Theta_0\left(1 - e^{-\frac{cl}{D}}\right)}{SpM\ \Theta_0} = 1 - e^{-\frac{cl}{D}}$$

(The symbol Sp stands for specific heat of gas at constant pressure.)

Equation (10) states that the true efficiency of the boiler flue depends only on its length and diameter and not on the initial temperature, or, that it is constant for the same boiler.

As shown by the curves in this paper, this equation is very nearly correct for low initial temperature and velocities of gases exceeding the critical values.

For cases where velocities below the critical values, Reynold's equation (3) would probably come more closely to the truth. For high initial temperature when the true boiler efficiency drops perceptibly with increasing velocity, on account of the rapidly increasing capacity, equation (5) can be modified for the increasing capacity.

Since in the equation

$$(5)\quad H = c'wv\ (T - t_1),$$

t_1 is the temperature of the adhering film of gas, or, as we call it the temperature of the dry surface, it (t_1) varies with the capacity, as has been explained in the section on conduction of heat through the heating plate. If then, in the above equation t_1, instead of being taken as a constant, is expressed in terms of the heat transmitted per second per unit of heating surface, equation (5) will agree for a considerable range of velocities with the experimental values. Such modified equation can be derived in the following way:

$$(2)\quad H = \frac{c}{d}(t_1 - t),$$

$$t_1 = H\frac{c}{d} + t.$$

Substituting this value for t_1 in equation (5) and simplifying, the equation becomes

$$(11)\quad H = \frac{c\ w\ v\ (T - t)}{1 + \frac{c}{d}\ c'\ w\ v}$$

Again let M be the weight of gasses passing the heating surface of the new flues per second, then since $w = \frac{c''}{T}$ and $v = c'\ MT$, $c'wv = C_1M$, where C_1 is a new constant.

$$\text{Let } C_1\frac{c}{d} = K, \text{ and } (T - t) = \theta;$$

substituting these values in equation (11) it becomes

$$(12)\quad H = \frac{C_1\ M\ \theta}{1 + K\ M}$$

and the heat absorbed by any elementary length of heating surface per second is

$$-SpM\ d\theta = \frac{C_1\ M\ \theta\ dl,}{1 + K\ W} \quad \text{or}$$

$$(13)\quad -\frac{d\ \theta}{\theta} = \frac{c\ dl}{1 + K\ M}$$

integrating (13) and getting constant of integration as before

$$\theta_l = \theta_0\, e^{-\frac{c\ l}{1 + KM}}$$

The true efficiency of the heating surface then is

$$(14)\quad E = 1 - e^{-\frac{cl}{1 + KM}}$$

Equation (14) states that the true efficiency of any given boiler depends only on the weight of gas passing over the heating surface.

By substituting any two experimental values beyond the critical velocity for E the only constants *c* and *K* can be determined. With these two constants determined for any one initial temperature, equation (14) will give a curve which will agree almost exactly with the curve determined experimentally, provided that the velocity is beyond the critical value. As seen from the curves determined experimentally the true boiler efficiency for the different initial temperatures do not coincide. It is evident that if the above equation is to conform with every curve, the constants would have to be determined for every temperature, which is a weak point of the equation. Further study of the experimental values and modification of the equation is necessary before it can be used generally. It seems, however, that the direction taken by Prof. Reynolds and followed by Prof. Perry in rational study of the problem of heat impartation to the heating plate of the boiler by convection is the right one, and is indeed well worthy of further investigation.

CONCLUSION.

According to the theory advanced by Prof. Osborne Reynolds and followed by that of Prof. John Perry, the rate of heat impartation to the dry surface of the heating plate is mainly proportional to,

(1.) Temperature differences of the gas and the dry surface of the heating plate.

(2.) Density of gas.

(3.) Velocity of the gas parallel to the dry surface.

The following explanation, will perhaps, help in understanding these factors.

Considering (1): this is the only factor usually thought of and is perhaps self evident.

Considering (2): it is plain that it is the individual molecules of gas whch give up their heat by vibrating against the dry surface of the heating plate. The greater the number of molecular impacts per second against any unit of area of the dry surface, the greater the amount of vibration (heat) imparted to the molecules of the dry surface. But the number of molecular impacts is directly proportional to the density of the gas which at a constant pressure varies inversely as the absolute temperature. On this account there is a direct neutralization of gain when striving for high temperatures in steam boiler practice, for, as the temperature is raised, the number of molecules in action against any unit of the dry surface of the heating plate is reduced.

Considering (3): a mental image should be formed of the appearance of a cross-section of intensely magnified dry surface of the heating plate. The molecules of the solid soot would probably appear to be in an extremely rapid state of vibration, with spaces between them much larger than the molecules themselves. Entangled among the outer molecules would be molecules of gas held close together in a dense film next to the soot, or metal in case of an absolutely clean boiler; farther out normal gas is reached where the molecules are widely scattered. All these gaseous molecules, from those entangled among the molecules of the soot to those in the gas of normal density would be in an invisibly rapid state of vibration; however, those close to the soot would be more or less bound by the attraction of the solid soot. Now, gas is a very poor conductor of heat and if we depended on its conduction the process of transferring heat from the moving gas to the adherent film would be very slow indeed. The only quick way of getting heat into the adherent film of gas is to dislodge the slowly vibrating cold molecules, from this adhering film of gas and replace them by rapidly vibrating hot ones. It can be imagined that as a stream of hot gas moves along the adhering film, an average of one third of its molecules are vibrating back and forth perpendicular to the surface and the dislodging, or scrubbing effect of these moving molecules on the molecules of the adhering film is proportional to the velocity of the mass of gas parallel to the heating plate. Thus it is that the velocity of gasses along the heating surface is an important factor in the heat absorption. It is this dislodgment that makes a boiler respond in amount of steam made to any reasonable demands put on it.

It remains to say a few words about the endurance of the electric furnace. With temperature up to about 900 deg. F. there was no particular trouble but when the temperature of air was raised to 1200 deg. F. and 1500 deg. F. the nickel wire seemed to crystallize and become very brittle after cooling, and failed by fusing after being in use 10 hours every day for 6 to 10 days.

It must be understood that in order to get the temperature of air to 1500 deg. F. the coils are with extremely high or low drafts brought close to the point of fusion (2600 deg. F.)

The asbestos slate was found to be easily workable material, and stood the temperature of the furnace very well. Asbestos shingles were found to be more durable at high temperatures than the asbestos lumber as it is called by the maker.

The St. Louis branch of the Keasbey and Mattison Co. furnished free of charge a number of these shingles for trial for building the furnace.

DISCUSSION.

President Abbott: A few years ago the Government was induced to institute as an annex to its Geological Survey—a Fuel Testing Department. At that time it was commonly supposed by the Government officials (as it was by a great many other people), that the mere testing of different kinds of coal under a boiler to obtain the evaporation per pound of water per pound of coal would produce information of value. On this supposition a Testing Plant was built and a great many fuel tests were made. It did not take a great length of time for the gentlemen in charge of these tests to come to the conclusion that merely testing coal in a particular apparatus with boiler and furnace had no general significance and was of no general value. Perhaps saying "no general value" is almost too broad, but it certainly did not have the value which it was originally supposed it would have. The engineers in charge of this testing work of course came to this conclusion before the Government officials did, and since then (I am guessing at this now) they have been trying to coax the Government officials to consent to a modification of the work; or, where they could not get the Government to consent to the modification they made it anyway without saying just what they were doing.

It is apparent that when a careful test is to be made, no results of any significance can be obtained if there are two or three or a half dozen variables present in the test; it is necessary to eliminate or "fix" all of the variables except the one that is being tested. In making a coal test—so called—one is really testing the *boiler*, the *furnace*, and the *coal*, while the skill and conscientiousness of the firemen also play quite an important part, and, as Mr. Kreisinger says, when they came to analyze their work—separate the performance of the boiler from the performance of the furnace—it was found that there was no data available upon which to fix the relative efficiency of either. Therefore they instituted a series of tests upon the boiler, in which they eliminated the fuel, the furnace and the firemen; they had left merely a boiler supplied with hot gas and it is these results which Mr. Kreisinger has presented this evening.

I am not aware that similar tests have ever been made before—certainly I have never heard of them—and to these gentlemen great credit is due for the valuable results they obtained with the meager facilities at their disposal, which results doubtless will aid in solving some of the vexatious questions that have long been a source of contention among boiler designers and boiler users.

Mr. A. Bement, M.W.S.E.: This Society and engineers in general I think, are under great obligations to Messrs. Ray and Kreisinger for presenting to us the results of their experiments, and for showing that velocity has an important influence as affecting heat obsorption, and it appears that credit is due to them for bringing this mattr to the attention of engineers, although others appear to have had a conception of the matter, as a fact in physics rather than a matter of importance in engineering practice. They should have the support of engineers in their effort to continue this work in connection wth the U. S. Geological Survey investigations. I hope that the Government and engineers in general will realize the importance of the experiments and see to it that they be continued.

The first experiments of this character with which I am familiar, were made in the Harrison Street electric power plant, of the Common-wealth-Edison Company in Chicago, early in 1903, or, some four years ago, wherein the single gas pass in Heine boilers was changed by an insertion of baffles, which formed *three* passes among the tube surface in place of the original *one*. With the single pass the gases left the boiler at a very high temperature, resulting in a correspondingly low efficiency, Mr. Abbott, now President of this Society, stated this condition could be remedied by the insertion of baffles among the tube surface, as shown in Fig. 1, illustrating one of them as laying above the eighth row of tubes and the other above the fourteenth row, causing the gases to flow the length of the boiler three times instead of only once, as in the original installation which is shown in Fig. 2. These baffles were inserted and careful tests made, which showed that this change caused some 30 per cent more work to be performed with a pound of coal than in the boilers without the baffling.

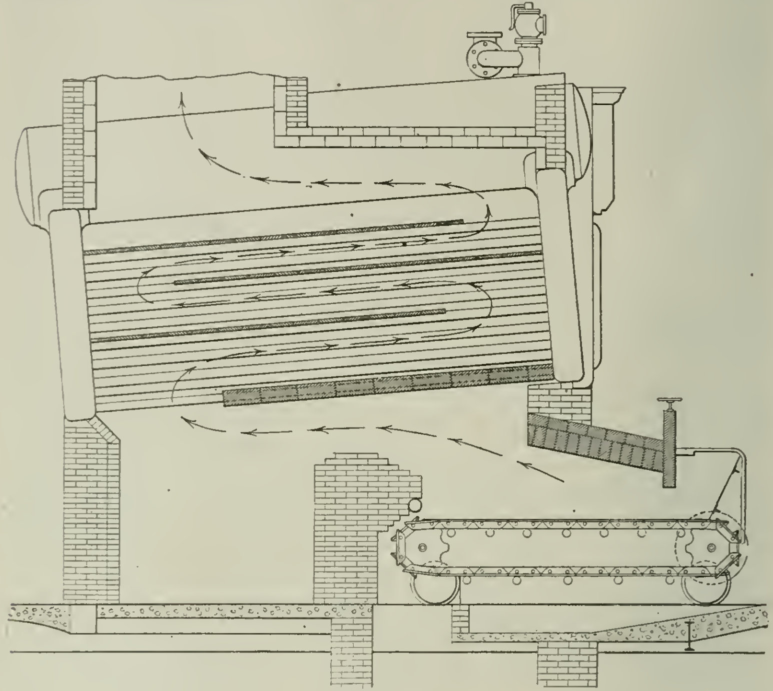


Fig. 1.

These experiments have been described elsewhere* and until the experiments set forth by Messrs. Ray and Kreisinger, it did not occur to me that increased velocity of the gases due to the more contracted gas passages had any influence on the result, although in discussing my paper which gave the results of the tests, before this Society, Mr. C. H. Hurd stated that an increase in velocity of flow of gases would be caused by reduction in area of the passes. It has been generally considered that increased temperature in escaping gases under such conditions, was due to more heat being supplied to the heating surface, (quoting Prof. Wm. Kent's words) "than it could properly absorb," the idea no doubt being that greater resistance to the flow of heat from the gases to the water, was caused by increase in temperature of the heating surface; and from measurements made among the tube surface of the plain boiler shown in Fig. 2, it was apparent that the current of hot gases flowed diagonally from the lower back corner to the front upper one; therefore when a large amount of heat passed through the boiler,

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* This Journal, Vol. IX., p. 44. Transactions American Society of Mechanical Engineers, Vol. 26; p. 619.

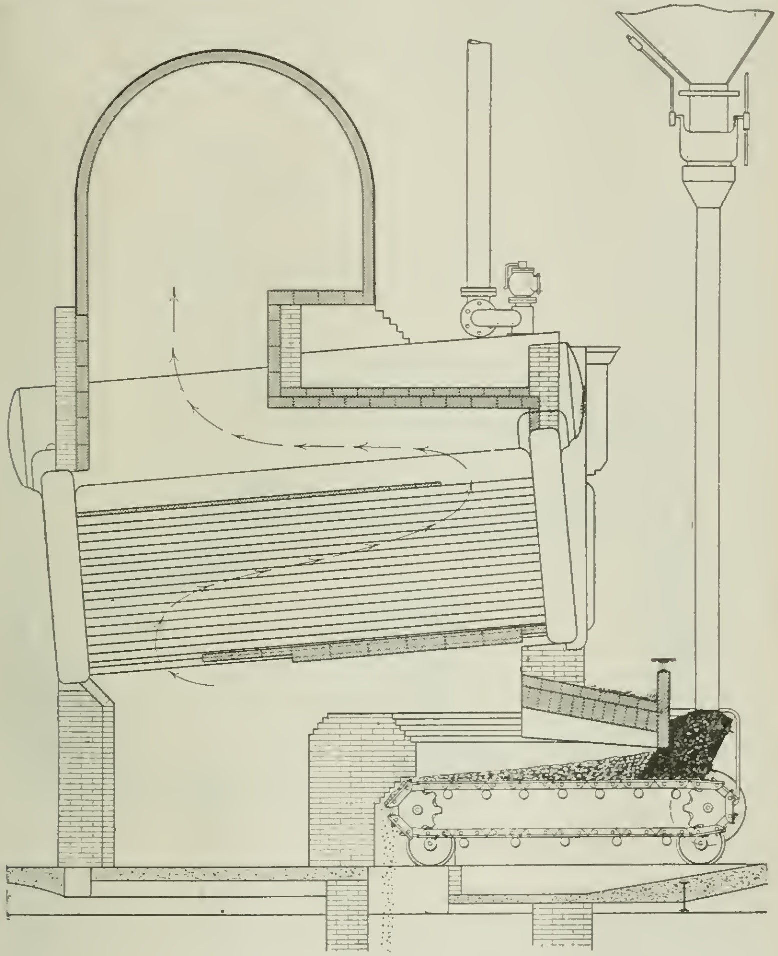

Fig. 2.

it took the same course as a small amount, or in other words, a larger quantity of heat was discharged upon approximately the same amount of surface, which would tend toward the belief that decreased efficiency was caused by the greater resistance to the heating surface, which would easily lead to the assumption that the larger efficiency secured with the increased passes shown in Fig. 1 was due to the gases being led over all of the surface of the boiler instead of only a portion of it.

Referring to diagram No. 9 in the author's paper, it appears that when the same quantity of gas at the same temperature in each case is passed through a narrow and long tube, and through a shorter and larger one, that the temperature is reduced more in the narrow and long tube than it is in the large one, notwithstanding the fact that the surface is as great in the larger tube as it is in the one of small diameter; from this it appears that under the condition of higher velocity, more heat is absorbed, unless it can be shown that the gases in the large tube flowed along the upper surface instead of acting upon all of it, which may have been the case. That the velocity has an effect is, of course, reasonable, as proven by many familiar examples, to-wit: if we blow air by fan or other means on an object which is of a higher temperature, it will be more rapidly cooled than if air of the same temperature but not in motion surrounded it; or on the other hand, if the air be warmer than the article, it will be heated more rapidly therefrom if the air flows at a velocity, than if it surrounds the object and is not in motion. It is, therefore, entirely reasonable to conclude that velocity must cut a figure of some considerable importance. I am, however, inclined to think that the authors place too much stress upon its value, and I would call attention to

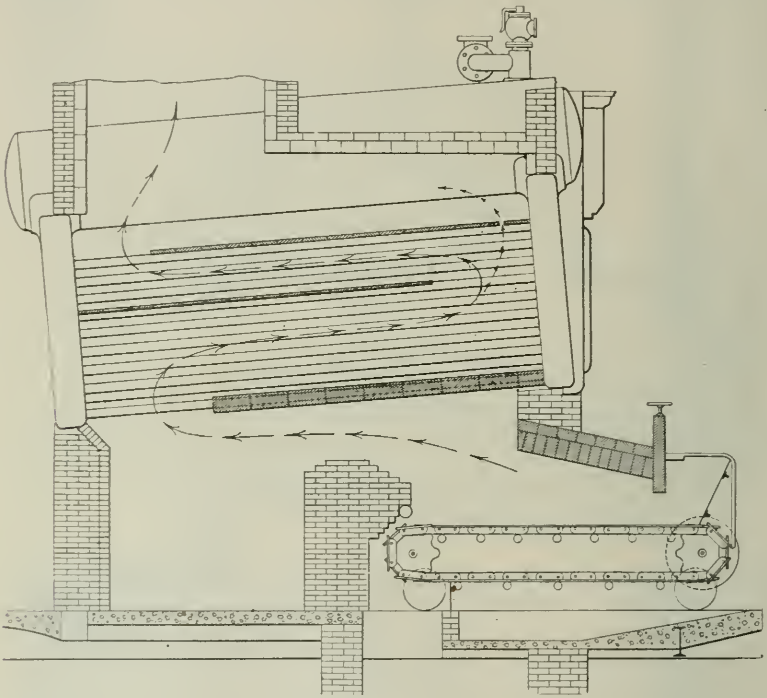

Fig. 3.

the fact that velocity in itself can have no direct influence on the transmission of heat and that it can only displace colder gas near the heating surface and cause warmer gas to take its place, and therefore after all, the heat transmission is dependent upon *temperatures* rather than velocity, the latter only being the means by which the higher temperature is brought to act upon the heat receiving surface, and I think the paper underestimates the importance of high temperature. We know by extensive experience with boilers, that in every case were combustion is complete in the furnace, that the highest efficiency is obtained with the greatest initial temperature, unless, of course, foreign influencing conditions do not affect the problem, and I am very glad that Mr. Ray in his discussion has called attention to the fact that they have discovered in their experiments an indication that at high capacity, water circulation in the model boiler used, was not sufficient to prevent the temperature of the tube surface raising an amount which may have influenced the outcome, and tended materially to produce the result indicated in the diagrams which show that after the point of critical velocity has been attained, the proportion of heat transmitted is practically constant. My own opinion is, that while velocity cuts an important figure, the fact that a greater proportion of the heating surface is acted upon by gases in the case, for example, of passages of small area as compared with large ones is also one factor of importance, and it may be difficult to ascribe a proper value to each. It has, however, been positively proven in the Commonwealth-Edison Company's experiments, that when approximately the entire boiler surface is acted upon by hot gases which were necessarily conveyed in a larger number of passages of smaller area, a much larger absorption of heat occurs, and we are enabled to take advantage of this fact, even if we do not know exactly what caused the result; this leads to the probable conclusion, that with the Babcock & Wilcox type of boiler, it would be an advantage to cause the gases to flow across the tubes in *five* passes instead of three as is now the common practice, and from my experience it would seem reasonable to expect that such a boiler with five passes would show as high a capacity as one with three, and in this connection it is interesting to note that the boiler with three passes (shown in Fig. 1) which produced about 30 per cent more steam for the same amount of coal, also increased the horsepower 3.5 per cent over that secured with the unbaffled boiler Fig. 2, and the arrangement shown in Fig. 3 with one baffle causing two passes, resulted in an increase in work per unit of fuel of 10 per cent, with an increase in capacity also of about 3.5 per cent over that of the unbaffled boiler, showing that with the more complex baffling and the more restricted passages, a sufficiently larger portion of the heat is absorbed to more than counteract the reduced amount of coal burned, owing to the lower draft at the fire caused by the restriction of the narrower passes; it is quite remarkable how nearly constant the capacity remained under these three conditions, notwithstanding that the baffling was carried to such an extreme. The efficiency with the single baffle shown in Fig. 3 is proportionately less than with the more complex, and it may be reasonable to assume that this is due in a measure to the much lower velocity in the flow of the gases in this boiler of the single baffle than in that of Fig. 1, as well as less tube surface being acted upon by the hot gas.

The economic significance of this matter should not be lost sight of when the fact has been taken into consideration that an expenditure of about $300 in placing baffles in a boiler of this character, will not only slightly increase the capacity but effect a fuel saving equal to or greater than that obtainable in an economizer installation, which might cost as much as the boiler itself.

One of the objects of the authors is, no doubt, to bring the matter to the attention of engineers and to solicit their interest and criticism. Assuming this to be the case, I think the value of the work will be much enhanced if the results of the Commonwealth-Edison Company's experiments be incorporated in their report. I also feel that much credit is due to the Commonwealth-Edison Company's engineers in this connection, because Mr. Ray was in a measure identified with its experiments, and that before he left Chicago, some of his friends presented him with a copy of The Steam Engine and Gas and Oil Engines, by Perry, wherein this theory of velocity was set forth, and which led to the planning of the experiments which Mr. Kreisinger has so well carried out.

I think the title of the paper is not the best one that could have been employed, because the experiments described by the authors do not deal with boilers or with boiler efficiency, but rather with the efficiency of *heating surface,* and I believe if this idea is kept in mind it will simplify the problem; therefore experiments were made not upon boilers, but upon heating surface arranged in convenient form for experimental purposes, as Mr. Kreisinger has stated.

One of the expressions used may be misleading. It is with reference to the flow of gases "parallel to" the heating surface. This would, no doubt, cause some people to feel that the Heine type of boiler would be more efficient than the Babcock & Wilcox, for example, because the general flow is lengthwise of the tubes instead of across, which, of course, is not what the statement means. Probably the expression of over or past the heating surface, would be better than parallel to.

The authors' diagrams employ the steam temperature as their base line, and it might be to advantage if the results of some of the tests were plotted, using the temperature of the atmosphere as a base line.

I observe that the authors intimate that transmission of heat to the boiler will be reduced if there is no direct radiation from the fire to the boiler surface. This is true, of course, in the abstract, although we must remember, that heat which does not radiate direct from the fire to the boiler, must necessarily find its way into the gases and be carried over the surface of the boilers to be absorbed by convection, and, therefore it will find its way into the boiler just the same. It is probable that if we could obtain a perfect condition of combustion with the fire exposed directly to the boiler surface, that the final efficiency in steam generation would be higher by a very small fraction of one per cent than if radiation were cut off, because if some heat is radiated directly from the fire, then there is left a smaller quantity to be transmitted by convection, and for that reason transmission would be more thorough, although the difference is so slight that it would be difficult or impossible to estimate it. From a practical standpoint, however, in those cases where tile roof furnaces are employed, all the radiation from the fire to the boiler is cut off excepting a very small amount finding its way from the hot tiles to the boiler tubes. With this method of furnace construction, however, final efficiency in steam generation is very much higher, when burning bituminous coal, than with any arrangement wherein the tubes are exposed to the fire, on account of the better combustion secured with the tile roof.

Recently I have compared extensive data from the performance of Babcock & Wilcox boilers equipped with chain grate stokers, wherein the tubes of the boiler were exposed to the radiant heat from the fire and the gases allowed to pass immediately among them directly from under the ignition arch, and also from tests of a similar boiler equipped with a tile roof and served with a chain grate, in which arrangement the direct radiation from the fire was entirely cut off as far as possible by this roof; I found that for the same unit of boiler heating surface, and strength of draft at the fire, the tile roof apparatus evaporated 40 per cent more water, or in other words made 40 per cent more horsepower than the boiler wherein the tubes were exposed to the direct radiation of the fire, and did so with an important increase in efficiency. I wish to be particular in calling attention to this fact, because recently in a discussion of the boiler capacities obtained in the coal tests in the Geological Survey's plant at St. Louis, some members of the American Society of Mechanical Engineers stated, I believe, that in their opinion, the presence of the tile furnace roof caused lower horsepower to be realized than would have been the case if it had not been present. I do not wish that we should be misinformed concerning a matter of such great importance as this.

Mr. E. F. Smith, M.W.S.E: It has occurred to me that, in studying the relation of temperature of gases to true boiler efficiency and to the rate of absorption, we might arrive at a more accurate conclusion if we were to consider the relation of the average, or effective, temperature of the gases with regard to the average temperature of the water, rather than the initial and final temperature of the gases with relation to the temperature of the water. In other words, we know that the initial temperature is related to the final temperature in a manner which might be shown by some arbitrary curve and in considering those two limits it does not occur to me that we are reaching a true conclusion, as the *average* temperature of the gas, which has an important bearing on the heat transmission, may lie anywhere between those two limits. I would ask Mr. Kreisinger if any investigations have been made along that line, although of course I recognize that it would be very difficult to make the observations.

President Abbott: Mr. Smith's point is, I believe, that the transfer of the heat is proportional to the average temperature of the gas between its initial and final temperatures, and if so the average temperature should be used in the calculation.

Mr. J. L. Hecht, M.W.S.E.: There is, it seems to me, a close analogy between what this paper calls boiler efficiency and what we speak of as engine efficiency. When we say that an engine has 65 per cent efficiency we do not mean that we are changing 65 per cent of the heat units in the work. We of course mean that we are using 65 per cent of the theoretically available heat units which we know to be about 27 per cent; in other words, about 17 per cent actual efficiency. In boiler tests, when we say we get 75 per cent efficiency we do not mean that me may hope to get 100 per cent efficiency on that basis, and I think if the heat units which are not available for work in the furnace could be eliminated, so that the heat units which are available for work in the furnace amount to say 80 per cent (to assume arbitrary figures), we might hope to get 100 per cent of that 80 per cent. Then our statement of the boiler having a certain percentage of efficiency would mean more than it does at the present time.

Towards the end of the third paragraph, of the fourth page of this paper, there is a statement made which evidently means that as the capacity is increased in a boiler the efficiencyy is lowered. The statement referred to is as follows: "Thus we see that with the same conditions of the heating plate and the same initial temperature of the furnace gases, the temperature of the escaping gases will rise with increasing capacity. Any cause which with the same initial temperature of furnace gases tends to increase the factor $(t_1 - t)$, increases the loss up the stack and lowers the efficiency of the boiler by the same amount." I do not quite see how to reconcile that with the fact that invariably increased efficiencies are obtained with increased capacity. In fact they usually seem to be directly proportional to each other.

Another thing that has occurred to me is, of what value is a large part of this work for practical purposes, because in this case air was heated and put through tubes surrounded by water and heat was absorbed. The question of excess of air does not enter in. It is my opinion that in actual boiler performances the reason we get better efficiency with increased capacity is that we cut down our excess of air, burn more coal and get more nearly the theoretical quantity of air. For that reason I think some of the results given in this paper may be directly the opposite of what we might expect to happen in a boiler under practical service.

Walter T. Ray, M.W.S.E. (by letter): Although my name appears as one of the authors of this paper, I really did little of the work; the primitive conception of the method of attack was mine; and I laid out the general lines along which the apparatus might be built, and the general character of tests to be run. My original ideas were considerably modified and all details of design and testing were studied out and executed mostly by Mr. Kreisinger. Mr. Chas. E. Augustine was exceedingly valuable as the mathematical calculator of tests. Messrs. Fred J. Bird and Carl J. Fletcher ran most of the tests. We desire to thank Prof. L. P. Breckenridge for the immediate interest he took in all the work, and Prof. J. A. Holmes and Mr. H. M. Wilson (of the Geological Survey) for their interest and indirect aid.

I thought it best to relegate certain remarks, following hereafter, to the discussion, that they might pass as personal opinions and not in any way commit the Geological Survey.

As to the general method of attack, physicists may well make the valid criticism that we should have carefully determined the actual temperature of the metal of the fire tubes, which is certainly always some warmer than the surrounding water; it is absolutely true that the temperature of the metal of the tubes is the lower limiting temperature of cooling the gases, and not the temperature of the water. The vital question is whether the metal is one-tenth degree warmer than the water, or ten or one hundred degrees. After a careful consideration it was decided that for such low temperature as we should work with the first few months, the difference would not be very disturbing. My personal opinion is that this conclusion was verified for the lower temperatures of the entering-air, but that for the higher temperatures it was rendered doubtful; for instance, when using the high furnace temperatures the true boiler efficiency fell gradually with increasing heat transmission, which falling I believe was mostly due to an increasing rise in tube-metal temperature, due to water circulation failing more and more to keep up with demands on it.

A factor of policy also had weight.—engineers are seldom physicists, and they are slow to trust boiler investigations made on apparatus which looks not the least like a boiler; whence we adopted multitubular boilers.

The most important factor was our inability to think of a feasible way to measure tube-metal temperatures at many points. This will be done at the Jamestown Exposition on large boilers when working at various capacities and combustion-chamber temperatures. Any future experiments with laboratory apparatus will be modified according to data obtained on the large boilers.

For certain reasons this work is now discontinued, and it is questionable whether it will ever be resumed unless there is a strong demand from the engineering public for further investigation of heat transmission and boiler efficiencies. If the work be continued it will be closely along the following lines:

(1) Continuation of tests on small models of multitubular boilers, using the three lengths of 8, 16 and 24 inches; each length to be tried with several tube diameters; and each of the many above mentioned boilers with several temperatures of entering air, and several velocities of entering air. Better provision would be made for effective water circulation. To complete the above investigation would require thousands of tests, occupying about twice as many hours, and the time would be unavailable. Fortunately at least two-thirds of the tests can probably be omitted after more is learned of the nature of true boiler efficiency.

(2) After the simple multitubular boiler is reduced to a mathematical basis, the step should be made to water-tube boilers, where all conditions are far more complex. The researches should be made with closely governable water circulation inside the tubes, as well as closely governable air flow outside of them. The following factors should be systematically investigated one at a time and in combination:

Outside diameter of tubes.
Distance apart of tubes center to center in each row.
Distance apart of rows of tubes, center to center.
Effect of staggering rows of tubes.
A careful investigation of draft absorption in all the above cases.

Inasmuch as expenditure of work on such experiments has now ceased, readers will confer a favor on the authors by informing them of any work done along these lines in this country or England or in Europe; it is our intention to attempt on our own time a mathematical co-ordination of any reliable tests we can get hold of.

When thinking of draft one must remember that it is used up perhaps in two nearly independent ways, (1) by scrubbing the heating surface, which is the desired effect, and (2) by contractions and expansions of cross-section of flow, the loss due to which, is accompanied by scarcely any benefit. If boilers are hereafter to be worked much harder than now, useless absorption of draft will have to be greatly reduced by intelligent arrangement of baffles and heating surfaces, the fundamental data for which arrangement can not now be had.

I believe that very few forced and induced draft fans have a high efficiency, because the air must enter and leave the blades with considerable shock, since the blades are usually radial. If boilers are to be made to absorb ten times the heat per square foot of heating surface than now, high forced and induced drafts will be necessary, and the fans will have to be efficient. At best they will probably use up several per cent of the steam generated. The saving in interest on investment in the plant will far more than counterbalance the loss of power in draft production, especially when we consider that boilers and furnaces may possibly be made ten or fifteen per cent more efficient than they usually are now.

On attempting to force up steam output per square foot of heating surface, per square foot of floor space and per dollar invested, the greatest troubles will be had with the fuel bed and furnace: the treatment of this subject is beside this paper.

L. P. Breckenridge, M. W. S. E. (by letter): The results of the experiments reported in this paper certainly present many suggestions for thoughtful consideration. The term efficiency has long been used so loosely in technical literature that one is seldom sure of its significance unless it is carefully defined by each writer who uses it. This has been done in this paper at the bottom of the first page of the article. The definition given is

$$\text{True Boiler Efficiency} = \frac{\text{Heat absorbed by the Boiler}}{\text{Heat which is available for it.}}$$

The numerator of this fraction is readily understood but just what amount of heat is represented by the denominator might easily be given a wrong interpretation unless the thoughts of the authors are carefully followed. It would seem, therefore, worth while to point out that in this discussion the term boiler is restricted to just that metallic vessel which holds the water to be evaporated and that only the heat absorbed by the water in this vessel is inclined in the heat considered in the numerator of the above fraction. One reader will think perhaps that the heat available for the boiler refers to the heat contained in the coal fired as determined by the coal calorimeter, another that it refers to the heat in the dry coal fired less the heat in the refuse drawn from the ash pit, others will doubtless remember to make some allowances for that fine ash which is drawn over the bridge wall and they will also allow that the boiler can not absorb heat from escaping gases whose temperature is even the same as the temperature of the water inside the boiler, and the proper allowances will also be considered for radiation losses. There are, however, still other losses which must be considered and which are not always much thought of in these problems.

If when coal is burned in a boiler furnace the combustion is incomplete, because of lack of sufficient air supply or because the absence of proper mixing devices prevents the necessary intermingling of the air with the carbon particles, or because the already properly mixed gases are reduced in temperature by coming in contact with cool surfaces of the boiler then there cannot be *evolved in the furnace* the heat which is available in the coal. Those who have experimented in this interesting field will know the difficulties that are to be encountered when attempting the determination of the *actual heat evolved in the furnace.* It is only, however, when we know just what the amount of this heat is that we can be ready to determine the value of the denominator of the fraction in the expression for the true boiler efficiency. It has seemed well, therefore, to call attention somewhat at length to the many factors which must enter into the problem of "true boiler efficiency" as this term is used in the paper here under discussion. The determination of heat transfer through boiler tubes and the factors which effect such transfer are of much importance in boiler operation and construction and all such work as is here presented should be gratefully received.

CLOSURE

Mr. Kreisinger: I wish to thank the president of this society and also the other gentlemen here who have taken part in the discussion of the paper.

It may appear, as Mr. Bement says, that we are placing too much stress upon the velocity factor as affecting the rate of heat transmission and overlooking the importance of the temperature. In writing the paper we thought no arguments were needed to convince the reader that the rate of heat transmission depends on the difference of temperatures of the gas and the dry surface. The importance of the temperature factor is generally admitted; in fact it was thought by many engineers, and even the older physicists, that the rate of heat transferance from a gas to a metal plate depended only on the difference of the temperature of the two. The velocity factor, in our opinion, needed strong arguments and experimental proofs in order that its importance might be admitted.

The fact that in our paper we used the term, "true boiler efficiency," which, with the same boiler is nearly independent of the initial temperature, may convey the idea that we intended to impress on the reader that high initial temperatures are not needed for good performance in boiler practice. This is not the case, for when we started in our paper to investigate the true boiler efficiency we meant to call attention to the fact indicated by our experiments, that beyond the critical velocity of the gas, a boiler will absorb nearly the same percentage of the heat available for absorption, as far as heat impartation by convection is concerned, no matter what the initial temperature is. It may be easily shown that with higher initial temperature more heat is available for absorption, and consequently a greater percentage of the total heat generated is absorbed, which means that the ordinarily used boiler efficiency (heat absorbed by boiler divided by heat generated) increases with the rise of initial temperature.

It may be well to stop here and explain more fully what the true boiler efficiency is, and how it is related to boiler efficiency as ordinarily used. The true boiler efficiency was devised by the Steam Engineering Division of the U. S. Geological Survey, because it seems to be the only true measure of the ability of the boiler to absorb heat. All other boiler efficiencies used in commercial tests make the boiler responsible for not absorbing heat not available for absorption. Perhaps the best way to make this matter of boiler efficiency clear is by using diagrams in which quantities of heat are represented by areas.

Supposing 1 lb. of combustile having 12,000 B.t.u. is burned completely and the gaseous product of combustion is 20 lbs. Assuming for the sake of simplicity, that the specific heat of the gases is 0.25, the temperature of the product of combustion will be 2400 deg. F.

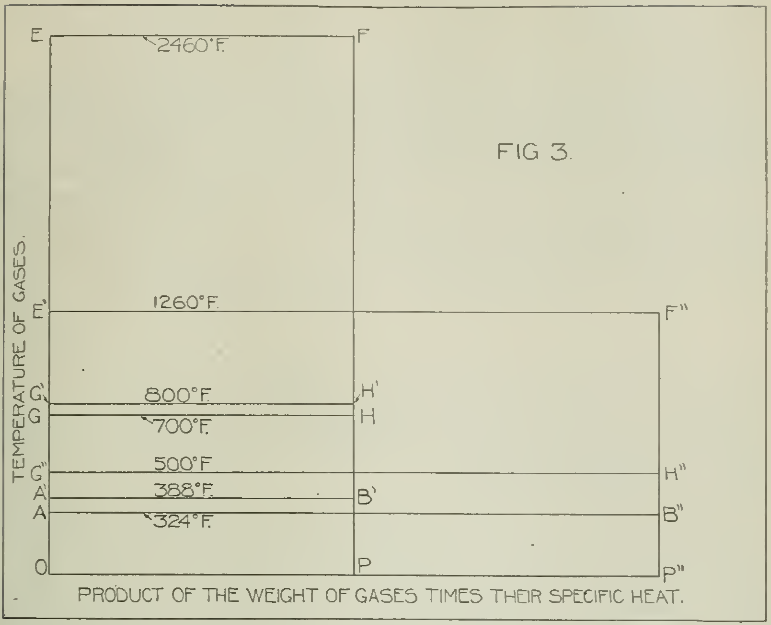

FIG 3.

above the temperature of the atmosphere. Then if in Fig. 3, the temperature is used as ordinate, and the product of the weight of gases multiplied by their specific heat as abscissae, the heat generated by the burning of the combustile is represented by the area O E F P. Supposing this hot gas is passed under a boiler generating steam under a pressure of 80 lbs., which makes the temperature of the boiler water about 324 deg. F. Let the line A B indicate this temperature. Then of the total heat generated, only the heat above this line, or, the heat represented by the area A E F B, is available for absorption. The remainder of the heat represented by the area O A B P, being below the temperature of the water in the boiler, cannot be absorbed.

It is only this available heat A E F B which an ideal boiler can absorb, and it is therefore taken as the basis for measuring the heat absorbing ability of a boiler. Now, suppose the boiler cools the gases down to 750 deg. F., which temperature is indicated in the diagram by the line GH, then the heat absorbed by the boiler is represented by the area G E F H. The true boiler efficiency is given by the ratio of the area G E F H to the area A E F B. And if the temperature of the atmosphere is taken at 60 deg. F., indicated in the diagram by line OP, the boiler efficiency ordinarily used is given by the ratio of area G E F A to the area O E F P. The numerical values of the two efficiencies in this assumed case are:

$$\text{The true boiler efficiency, } E_4 = \frac{2400 + 60 - 750}{2400 + 60 - 324} = 80\%$$

$$\text{Efficiency as ordinarily used, } E = \frac{2400 + 60 - 750}{2400} = 71\%$$

If instead of the steam being generated under 80 lbs. of pressure, it is generated under a pressure of 200 lbs., then the corresponding temperature of the boiler water is 388 deg. F. Thus less heat is available for absorption, and less heat will be absorbed by the boiler even though the ratios of the two heats may remain the same. Taking the temperature of the escaping gases in this case to be 800 deg. F., the two boiler efficiencies are:

$$\text{True boiler efficiency, } E_4 = \frac{2400 + 60 - 800}{2400 + 60 - 388} = 80\%$$

$$\text{Efficiency as ordinarily used, } E = \frac{2400 + 60 - 800}{2400} = 69\%$$

This second case shows that although the rise in steam pressure may not effect the true boiler efficiency, it lowers the boiler efficiency. as ordinarily stated.

Again, supposing the same 1 lb. of combustile is burned completely, but with a resulting weight of the gaseous product of combustion equal to 40 lbs.; the temperature of the product will then be only 1200 deg. F. above atmospheric temperature. Although the same quantity of heat is generated as in the first case, twice as much heat is below the temperature of the boiler water and therefore not available for absorption; the quantity of the heat available is smaller by the same amount. Thus, even should the true boiler efficiency remain constant, a smaller percentage of the total quantity of heat generated will be absorbed because less heat is available for absorption. Assuming the temperature of the leaving gases to be 510, then the two efficiencies are:

$$\text{True boiler efficiency, } E_4 = \frac{1200 + 60 - 510}{1200 + 60 - 324} = 80\%$$

$$\text{Efficiency as ordinarly used, } E = \frac{1200 + 60 - 510}{1200} = 62.5\%$$

In an extreme case so much air could be used for the combustion that the temperature of the product would be equal to that of the boiler water, in which case no heat would be available for the boiler, and therefore no heat would be absorbed by it. Thus it can be seen that the useful effect of the heat diminishes with the drop of the initial temperature of the product of combustion. It is, however, unfair to charge in the above cases the decreases in the useful effect to the boiler; in these cases the decrease should be charged rather against the furnace. Only the heat available for the boiler and not absorbed by it should be counted against the boiler.

It should not be inferred from the charts presented in our paper that since the true boiler efficiency of a boiler is nearly the same for all initial temperatures it does not matter how much air is used for the combustion of the fuel and that the useful effect will be the same.

The less air used for combustion the higher the temperature of the products, and provided that all the combustible has completely burned, the larger will be the quantity of the heat available for absorption, and even should the true boiler efficiency remain the same, the larger will be the quantity of heat absorbed by the boiler. With any given boiler the problem seems to be to make as much heat available for absorption as possible and the boiler will always do its best.

The expression "gases passing *along* the heating surface," will probably be misunderstood by many. I think that Mr. Bement's expression—"gases passing over the heating surface"—is better, as it includes both gas currents parallel and perpendicular to water tubes of a boiler.

With reference to Mr. Bement's suggestion that the title of this paper might more properly be stated "True Efficiency of Heating Surface," I will say that probably he is right, but as we started out in our work at St. Louis to call it "True Boiler Efficiency" we prefer not to make any change in the title now, as it might cause some confusion; or at least not until this other term is more generally adopted.

Mr. Smith asked whether we should not take the average temperature of the gases as they pass through the boiler, instead of using the initial temperature in the calculation. I do not think that this would be the correct way; it would certainly involve a very elaborate calculation, and as some assumption would have to be made, it is doubtful that such calculation would have any value. The arithmetical average between the initial and final temperatures of the gases would not be the correct average, because the drop of the temperature through the boiler is an exponential curve and not a straight line. In future experiments we intend to get this drop by actual measurements.

Mr. Hecht, I believe compared our true boiler efficiency to a steam engine efficiency similarly based on the heat available for transformation into mechanical energy. This is a good comparison. In testing steam engines we are dissatisfied if they do not transmit all the heat into mechanical energy although we know that a larger part of the heat given to the engine is below the atmospheric temperature, and is not available in the engine. For instance, of all the heat given to the engine perhaps only 30 per cent is available; the remaining 70 per cent of the heat is not available for the engine, as the latter can not reduce the temperature of the steam below that of the atmosphere.

In a special bulletin entitled "The Study of Four Hundred Boiler Tests," the Steam Engineering Division of the U. S. Geological Survey described and illustrated such true thermo-dynamic steam engine efficiency, and defined it as "the ratio of the heat converted by the engine into mechanical energy, to the heat available in the engine," counting all the heat which remains in the steam after the engine has expanded it adiabatically to the temperature of the atmosphere as not being available to the engine.

Mr. Hecht also said that the efficiency of the boiler increases with the capacity. That is probably the over-all efficiency of the steam generating apparatus; that is, the ratio of the heat absorbed by the boiler to the heat in the coal fired. This might be so in some cases because the latter efficiency takes in the efficiency of the furnace, grate and boiler. Perhaps in some cases the drop in boiler efficiency may be accompanied by a rise in furnace efficiency; then two multiplied together appear the same, or higher capacity may give slightly higher over-all efficiency. This may be so in a few cases, when the boiler is worked at a very low capacity; in general, however, it has been our experience that the over-all efficiency of the steam generating apparatus drops with the rise in capacity. I will refer Mr. Hecht to the special bulletin mentioned for proofs of my last statements, and also to discussion of boiler tests published elsewhere by various members of the Steam Engineering Division of the U. S. Geological Survey.

As to the last point brought out by Mr. Hecht, I will say that the real value of the experiments presented in this paper lies in the fact that the grate and furnace, and consequently the excess of air, have been eliminated. The purpose of these experiments was to study the heat absorption by the boiler, or, better, by its heating surface, and, as Mr. Abbott said, as no results of any significance can be obtained if there are two or three or half a dozen variables present in the tests; it is necessary to eliminate or fix all the variables except the one that is being tested. Since we were testing the heating surface of a boiler we have eliminated the furnace, the coal and the firemen, as these are varying quantities which would make the problem we wished to study very complicated.

There were made at the Government Coal Testing Plant at St. Louis about 500 boiler tests with more complete and accurate records than have ever been made before, and still the value of those tests was considered unimportant by many engineers because there were so many variables in each test that it is difficult to draw any definite conclusions. I shall again refer to the Government bulletin "Study of Four Hundred Boiler Tests" wherein there is a full discussion of most of the boiler tests made at the Government Coal Testing Plant, and where many conclusions were attempted.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE REGULAR MEETING, September 4th, 1907.

A regular meeting of the Society (No. 609), being the first meeting following the summer vacation, was held Wednesday evening, September 4th, 1907.

The meeting was called to order about 8:30 p. m. by President Abbott, with about 50 members and guests present. The Secretary read the Minutes of the Extra Meeting (No. 608), held June 26th, 1907, which were approved.

The Secretary reported from the Board of Direction that the following had been elected into membership:

	Grade.
Frederick Y. Parker, St. Louis, Mo	Active
Clifford W. Ozias, Strathmore, Alberta, Can	Active
Edward J. Gillen, Chicago	Associate

Also that the following had applied for membership in the Society:

Lathrop A. Bostwick, Dansville, N. Y.; transfer from Associate.
Roscoe G. Walter, Madison, Wis.
Louis J. Putnam, Janesville, Wis.
Peter M. Louwerse, Grand Rapids, Mich.
Henry J. Hunt, Madison, Wis.
Ralph P. Melendy, Grand Rapids, Mich.
John Hornbrook, Chicago.
A. Lovell, Chicago.
E. A. Carter, Chicago.
F. W. Thomas, Topeka, Kans.
R. W. Dull, Aurora, Ill.
C. W. Shepherd, Chicago; transfer from Junior Grade.
A. J. Duncan, Chicago.
J. W. Barrie, Chicago.
R. A. Ekstrom, Chicago.

Announcement was made of the death, August 30th, 1907, of Mr. Nelson A. Sager, Chicago, an Active member. Mr. Layfield offered a resolution that a Committee be appointed by the chair to prepare a memorial of Mr. Sager, which was carried.

The President made a short address on this the first meeting of the fall and winter session—recounting what had been done in the Society and the aim and desire of the Board of Direction for the benefit of the Society, the preparation of a program of papers for the meetings, which promised some good papers and wished for good attendance and a live interest in the meetings, and the papers to be presented.

The President then introduced Prof. D. W. Mead, M.W.S.E., who presented his paper on "Hydraulic Engineering at the University of Wisconsin." This paper having been printed and sent out in advance was not read, but a summary was given with lantern slide illustrations. Discussion followed from Messrs. Andrews Allen, H. W. Carter, E. E. R. Tratman, J. H. Warder, P. Junkersfeld, O. Strehlow, with a closure by Prof. D. W. Mead. The meeting adjourned about 10:20 p. m.

EXTRA MEETING, September 18th, 1907.

An extra meeting of the Society (No. 610), was held in the Society Rooms, Wednesday evening, September 18th.

The meeting was called to order about 8:20 p. m., with President Abbott in the chair and about 35 members and guests present.

The Secretary announced the recent death of an Active member of the Society, Mr. John C. Darst, which occurred September 5th, 1907. A resolutios was offered and passed that the chair appoint a committee to prepare a

Memorial of the late Mr. Darst. There being no other business to bring before the Society, Mr. Henry Kreisinger, M.W.S.E., was introduced, who presented the paper written by Mr. W. T. Ray and himself on "The Nature of True Boiler Efficiency." The paper (in major part as submitted) has been printed and sent out in advance.

Discussion followed from Messrs. W. L. Abbott, A. Bement, R. H. Kuss, E. F. Smith, F. J. Bird and J. H. Hecht, with a closure by Mr. Kreisinger.

The meeting adjourned about 10:20 p. m.

REGULAR MEETING, October 2d, 1907.

A Regular Meeting of the Society, (No. 611), was held Wednesday evening, October 2d. The meeting was called to order about 8:10 p. m., with President Abbott in the chair and over one hundred members and guests present. The minutes of the meetings held September 4th and September 18th were read and approved.

The Secretary reported from the Board of Direction the election into membership of the following:

Lathrop A. Bostwick, Dansville, N. Y.; transferred from Associate to	Active
Roscoe G. Walter, Madison, Wis.	Junior
Louis J. Putnam, Janesville, Wis.	Active
Peter M. Louwerse, Grand Rapids, Mich	Active
Henry J. Hunt, Madison, Wis.	Junior
R. P. Melendy, Grand Rapids, Mich	Active
John Hornbrook, Chicago	Junior
Alexander G. Duncan, Chicago	Associate
Raymond W. Dull, Aurora, Ill.	Active

Also that applications for membership in the society had been received from the following:

Otto S. Hansen, Chicago	Junior
S. L. Pierce, Chicago	Junior
Charles K. Mohler, Chicago	Active
Albert J. Schafmayer, Chicago	Junior
Russel J. Mershon, Chicago	Active
J. T. Walbridge, Chicago	Junior
Harold K. Weld. Elgin, Ill.	Junior
Charles E. B. Rilliet, Roosevelt, Ariz.	Active
F. S. Harvey, Chicago	Junior
Charles C. Lemmon, Elmhurst, Ill.	Junior
James R. MacKnight, Chicago	Junior
William K. Hatt, Lafayette, Ind.	Active
John W. Kendrick, Chicago	Active
Harold G. Macdonald, Chicago	Junior
Victor E. Ellstrom, Evanston, Ill.	Junior
E. W. Block, Chicago	Active
E. A. Carter, Chicago	Active

The Secretary also announced that certain amendments to the Constitution and By-laws had been prepared and had been considered favorably by the Board of Direction, and were recommended by them to the Society; that the amendments would be printed and sent out to the membership, and would come up for discussion at the next regular meeting to be held November 6th.

Announcement was made of the death, Sept. 1, 1907 of Mr. J. A. Lewis, an Active member of the Society since December 21st, 1892, the information having been received from Mr. Nathan Lewis of Youngstown, Ohio, a brother of our late fellow member.

A resolution was offered by Past-President W. H. Finley that a committee be appointed by the President to prepare a memorial of the late Mr. Lewis.

There being no further business to bring before the Society, the President, in a few happy words, asked Past-President Finley to preside over the meeting, as he was better informed on the subject of the evening. Mr. Finley, on accepting the Chair, introduced in a general way the subject for discussion as being a consideration of certain elements of bridge design.

Mr. Horace E. Horton, a Past-President, was then introduced, who read his paper, presenting some matter bearing on the design of open or latticed compression members—"Extension of Detail Specifications for Structural Steel Work to open Compression Members; the Relation and Proportion of Parts forming a built Channel or similar construction; also the lattice for the same."

Discussion and comment followed the reading of the paper from Messrs. A. Reichmann, T. W. Schaub, O. H. Basquin, C. R. Dart, W. C. Armstrong, A. von Babo, W. L. Abbott, and H. F. Moore.

A resolution was introduced by Mr. Reichmann, that the paper by Mr Horton be printed and sent out to the members, with the view of securing fuller discussion than seemed possible from listening to the reading of the paper. The motion was carried.

Mr. O. P. Chamberlain offered a resolution that another evening be set aside by the proper authorities for further consideration and discussion of the subject of Mr. Horton's paper, which was carried.

The meeting adjourned at 9:30 p. m.

EXTRA MEETING, October, 16, 1907.

An extra meeting of the Society (No. 613) was held Wednesday evening, October 16th, 1907. The meeting was called to order about 8:15 p. m., with Vice-President Andrews Allen in the Chair and about 55 members and guests present. There was no business to bring before the Society, so Prof. F. E. Turneaure, M. W. S. E., was introduced, who presented his paper on "Experimental Determination of Stresses in Web Plates and Stiffeners of Plate Girders." This paper had been printed and sent out in advance of the meeting.

Discussion followed from Messrs. Andrews, Allen, J. W. Ludlow, W. K. Hatt, W. G. Langenheim, O. H. Basquin, with a Closure by Prof. Turneaure.

The meeting adjourned about 9:45 p. m.

J. H. Warder, *Secretary.*

MINUTES OF THE ELECTRICAL SECTION, October 11th, 1907.

A regular meeting of the Electrical Section (No. 25), being an extra meeting of the Society (No. 612) was held Friday evening, October 11th.

The meeting was called to order about 8:15 p. m., by Mr. C. A. S. Howlett. Chairman, and with about thirty-five members and guests present. The Minutes of the 24th meeting of the Section held April 12th were not read, but were approved as printed in the Journal.

The Chairman made a few remarks relative to the work of the Electrical Section, and urged upon the members greater activity toward building up the Section in numbers, and in interest by securing or contributing papers.

Mr. W. H. Crumb was then introduced, who read his paper on "Telephone Rates for Large Exchanges." This was illustrated by a series of lantern slides of charts and curves, showing growth and characteristics of "traffic" in a large centre like Chicago.

Discussion followed from Messrs. W. F. Burgess, K. B. Miller, C. A. S Howlett, E. H. Freeman, A. R. Swoboda, W. A. Fricke, and W. H. Crumb.

The meeting adjourned about 10:20 p. m.

EXTRA MEETING. ELECTRICAL SECTION.

An extra meeting of the Electrical Section (No. 26) and of the Society (No. 614) was held Friday evening, October 25, 1907.

The meeting was called to order about 8:20 p. m. with Vice-Chairman. D. W. Roper in the Chair, and about 35 members and guests present.

There was no business to be brought before the Section, and after a few words of welcome and explanation from the Chair, Prof. Leon Gerard, of Belgium, an eminent scientist and engineer, was introduced, who presented his paper on "The Use of Electricity in the Purification of Water." The address was illustrated by a number of lantern slide views and some blackboard explanations.

After the reading of the paper the Chairman invited President Abbott to conduct the discussion. Before proceeding with the discussion, Past President O. Chanute proposed a vote of thanks to Prof. Gerard for the very interesting, very clear, and very important communication he has presented to the Society, which was unanimously carried..

Some discussion followed, mostly in the form of questions, from Messrs Albert Scheible, L. A. Ferguson, F. Chauvet, W. E. Williams, and Ernest McCullough, these questions being answered by Prof. Gerard.

The meeting adjourned at about 10:30 p. m.

J. H. Warder,
Secretary.

A CIRCULAR LETTER TO OUR MEMBERSHIP.

October 3, 1907

Dear Sir: Certain amendments to the Constitution and By-Laws properly presented in writing, with the necessary signatures of active members of the Society, have been received. These were announced at the Regular Meeting of the Society, October 2, 1907, and are now sent out to the membership for consideration. At the next Regular Meeting of the Society to be held November 6th, these amendments will come up for consideration and discussion, and afterwards to be voted on by letter ballot during November. If you cannot be present at the meeting of November 6th, your views or discussion of these matters can be sent to the Secretary by letter and will be presented at that meeting.

Very respectfully submitted,

J. H. Warder,
Secretary.

AN AMENDMENT TO THE CONSTITUTION, W. S. E.

TO BE PRESENTED AT THE REGULAR MEETING, NOVEMBER 6, 1907.

The undersigned, active members of the Western Society of Engineers, respectfully offer the following amendment to the Constitution of this Society:

In Article III, Section 4, add the following sentence:

His connection with this Society shall cease when he becomes thirty years of age, unless he be previously transferred to another grade, or unless the time be extended by action of the Board of Direction. This extension shall in no case exceed the time which the Junior still lacks for qualification to Active membership.

Article III, Section 4, of the Constitution will then read as follows:

A Junior shall be not less than eighteen years of age and a person who is not eligible as an Active member. He shall have had active practice in some branch of engineering for at least two years, or he shall have graduated from a School of Engineering of recognized standing. His connection with this Society shall cease when he becomes thirty years of age, unless he be previously transferred to another grade, or unless the time be extended by action of the Board of Direction. This extension shall in no case exceed the time which the Junior still lacks for qualification to Active membership.

(Signed),

Ralph Modjeski,
Bion J. Arnold,
C. D. Hill
G. M. Wisner,
W. L. Abbott,
W. H. Finley,
J. W. Schaub,

Edward C. Carter,
A. Bement,
G. A. M. Liljencrantz,
W. C. Armstrong,
E. N. Layfield,
John Brunner,
Charles L. Strobel.

AMENDMENTS TO THE BY-LAWS, W. S. E.

TO BE PRESENTED AT THE REGULAR MEETING, NOVEMBER 6, 1907.

The undersigned, Active members of the Western Society of Engineers, believing that certain modifications can be made in the By-Laws to the advantage of the Society, respectfully offer the following amendments:

In Article III, pertaining to "Duties of Officers and Committees," Section 2, fifth paragraph, (the creation of Standing Committees of the Board of Direction) after the words "Publication Committee" strike out the remainder of the paragraph and substitute the following words: "A Library Committee and a Committee on Amendments. Each of these Committees, except the Committee on Amendments, shall be composed of three Active members of the Society, at least one of whom shall be a member of the Board of Direction. The Committee on Amendments shall be composed of five Active members of the Society, three of whom shall be the latest Past-Presidents."

The fifth paragraph of Section 2, Article III, will then read as follows:

The Board of Direction shall meet within ten days after the Annual Meeting and shall then appoint the following Committees: A Finance Committee, a Publication Committee, a Library Committee, and a Committee on Amendments. Each of these Committees, except the Committee on Amendments, shall be composed of three Active members of the Society, at least one of whom shall be a member of the Board of Direction. The Committee on Amendments shall be composed of five Active members of the Society, three of whom shall be the three latest Past-Presidents.

Also amend Article III by adding a section after Section 7, to be called Section 8, as follows:

SECTION 8. The Committee on Amendments shall consider amendments to the Constitution and By-Laws, which may be referred to it by the Board of Direction, or which may be suggested by its members, and shall make a report at such time as will allow action by the Society during the current year.

Also in Article IV, "Admission to the Society," amend Section 4 as follows: Strike out the words, "The application shall be signed by at least three Active members to whom the applicant is personally known," and substitute therefor, "The applicant shall furnish the names of at least five Active members to whom he is personally known. Each of these shall be requested by the Secretary to address a letter to the Board of Direction, on a form prescribed by said Board, stating the extent of the writer's personal knowledge of the applicant and of his professional work. If at least five of the Active members named as references do not furnish the requisite endorsements, the Secretary shall call upon the applicant for additional names, and not until written communications shall have been received from at least five Active members shall the application be considered by the Board." After the words, "to be personally known to" strike out the word "three" and substitute the word "five." The entire Section 4 will then read as follows:

An application for admission to the Society as Active member or Junior, or for transfer from Junior to Active member, shall embody a concise statement, with dates, of the candidate's professional training and experience, and shall be in a form and in such detail as may be prescribed by the Board of Direction. It shall be signed by the applicant, and shall contain a promise to conform to the requirements of membership, if elected, and shall be accompanied by a deposit of five dollars to be applied on entrance fee if applicant be elected, or refunded to him if not elected. The applicant shall furnish the names of at least five Active members to whom he is personally known. Each of these shall be requested by the Secretary to address a letter to the Board of Direction, on a form prescribed by said Board, stating the extent of the writer's personal knowledge of the applicant and of his professional work. If at least five of the Active members named as references do not furnish the requisite endorsements, the Secretary shall call upon the applicant for additional names, and not until written communications shall have been received from at least five Active members shall the application be considered by the Board. Applications of Engineers who may be so situated as not to be personally known to five Active members may be recommended for membership by three members of the Board of Direction, after having secured evidence sufficient in their opinion, to show that the applicant is worthy of admission.

Also amend Article VI, Section 1, of the By-Laws by striking out everything after the words "transfer to another grade." This will then be as follows:

Article VI, Section 1. An entrance fee of twelve dollars and fifty cents ($12.50) shall be payable on admission to the Society by an Active member or Associate; and five dollars ($5.00) by a Junior; this sum to be credited against his entrance fee at the time of his transfer to another grade.

This amendment is recommended only in conjunction with the amendment to the Constitution to which it is related.

(Signed),

RALPH MODJESKI,	W. L. ABBOTT,
W. C. ARMSTRONG,	JOHN BRUNNER,
EDWARD C. CARTER,	G. A. M. LILJENCRANTZ,
E. N. LAYFIELD,	W. H. FINLEY,
J. W. SCHAUB,	CHARLES L. STROBEL.

BOOK REVIEWS.

SHAFT-SINKING UNDER DIFFICULT CONDITIONS: By J. Riemer. Translated from the German by C. R. Corning and Robert Peele. 6 by 9 ins.; 174 pages and index, with 18 engravings and 19 folding plates. John Wiley & Sons, New York. 1907. Cloth bound. Price $3.00.

Messrs. Corning and Peele have done a great service for those engineers in this country that are called upon to sink shafts in water-bearing ground, by their recent translation of the book of the eminent German shaft-sinking engineer, J. Riemer of Dusseldorf.

As pointed out by the translators in their preface, there is no exact parallel in this country to the geological formation found through considerable areas in northern Europe, and which were encountered in sinking many of the shafts described in this book. While in this country we have large areas covered with heavy glacial drift, like that found in Europe, and in places to great depths—350 to 400 feet—as in parts of Bureau County, Illinois, we have nothing akin, except posssibly along the gulf coast, to the great thicknesses of gypsum, marls, and other porous but semi-solidified sediments saturated by water and which are found in parts of northern Europe to depths of 1200 feet or more.

Nevertheless, the lessons to be learned from the experiences recorded, the set-backs and evolution of ingenious contrivances leading to success in sinking shafts through such difficult ground, will be of great value not only to mining engineers but to other engineers engaged in bridge foundations and in tunnel work. Such work frequently reaches the limit of depth of the widely used and comparatively simple pneumatic caisson method. This book describes the systems which have proven successful below the pneumatic limit and under the most severe conditions. These are grouped under four heads: Shaft-sinking by hand; Shaft-sinking by boring; The Freezing Process; Drop Shafts.

The first method is naturally the simplest, although the author cites several difficult shafts, as for example the Wintershall shaft in Thuringia, in which a flow of 1584 gallons per minute was handled, and the shaft sunk to 846 feet to where the water was shut off by the iron lining.

"'The method of sinking an entire shaft in a single boring, carried on under water, was first introduced by Kind." It is a method similar to boring wells with strings of tools, except that in the improved method a small advance boring is made, and then followed up by a cutting tool of the shaft diameter and sloped toward the center. In one instance the small cutter or "trepan" weighed 11 tons, and the large one 26 tons. An engine actuating a walking beam raises the tools to drop the same as in an oil well drilling outfit. A "sludger" from time to time takes out the drillings. A large hoisting engine is required to lift the tools to the surface, and everything has to be on a most massive scale. The lining is of cast iron rings, sometimes several inches thick, and sometimes weighing 4000 tons.

In view of the hap-hazard way in which many mining companies undertake somewhat troublesome shaft sinking in this country, it is of great interest to read of the care with which all the details are worked out in advance by Reimer and his asssociates, and the patience and perseverance with which obstacles are met, diagnosed and overcome.

A list of 79 shafts sunk by this method, called the Kind-Chaudron System, from 1852 to 1904 is given; some of these range up to 1200 feet in depth.

The Freezing Process is better known in this country through a compilation of records published a few years since in the Transactions of the American Society of Civil Engineers. Unfortunately we have had only one successsful application—the "Chapin Shaft" in Michigan of comparatively shallow depth—out of 64 examples tabulated from 1883 to 1904. The deepest of the shafts sunk by the freezing process was nearly 700 feet deep, and still sinking in 1904; but the majority are relatively shallow. Clearly the function of this process is to sink through unstable ground like real quicksand, for which both the boring and the hand sinking methods are inapplicable.

In the latter field the drop-shaft method competes, and, as pointed out, is the oldest method in use. Though in its earlier application the excavation was done by hand, the author does not take up the discussion of this, but passes to the modern method of excavating under water by means of the sack-borer, clam-shell buckets and water-jetting apparataus, and the discussion of the methods for lining the shafts under water, and the forcing of the same down with hydraulic-jack apparatus.

Enormous difficulties were encountered in the earlier shafts; Rheinpreussen No. 1 took 20 years and No. 2, 13 years to sink. On the other hand, later improvements allowed No. 3 to be sunk between 1892 and 1895, and No. 4 was finished in 1903 in two years. These shafts had to go about 500 feet to reach solid carboniferous strata, though all of this depth was not in loose sands or clays.

The author does not touch on the method of a moveable advance shoe or shield, which has been used with more or less success in sinking mining shafts in this country, but this system, while applicable in relatively shallow work, would not do for the heavy work required abroad. Among the most valuable features of the book are the photographic illustrations and the detail sections of typical shafts and views of the sinking apparatus. G. S. R.

STEAM BOILERS AND SUPPLEMENTARY APPLIANCES: A practical treatise on their construction, equipment and working, by William H. Fowler, Mem. Inst. Civil Engineers, London, etc. 5½ by 8½ ins. Cloth bound. Price 12s 6d net. Scientific Publishing Co., Manchester, Eng.

This is a well printed and illustrated volume of 619 pages with 572 engravings, purporting to treat the subject from a modern and advanced standpoint, which it fails however, to do, for two reasons.

First, the examples of boilers and associated apparatus which are shown and described, are almost all European types, more particularly English.

Second, there has been but little account taken of new developments in apparatus and methods of operation.

One would expect a new book to notice for example those improvements made in boilers, which have tended to increase efficiency, such as involved in gas baffling and furnace construction. It is also to be regretted that the matter of smokeless furnaces should have received only indifferent treatment, as it would have been possible to present a most satisfactory chapter on this important feature of boiler practice. The volume, however, is an excellent treatise on English practice, and as such will be of value to American readers, and should be in the library of every mechanical engineer. A. B.

The Design of Walls, Bins and Grain Elevators: By Milo S. Ketchum, C. E., University of Colorado, Engineering News Pub. Co., New York, 1907. 6½ by 9 ins. pp. 394, including 5 pages of index; 40 tables; 260 illustrations and 2 folding plates. Cloth. Price $4.00.

This is another valuable contribution to engineering literature from the pen of the Dean of the College of Engineering, University of Colorado, and like other of his books is worthy of consideration.

The subject of retaining walls—their stability to withstand over-turning or sliding—is of consequence to many engineers. Practice has shown that certain empirical rules give fairly satisfactory results; but to an intelligent engineer, such a "rule of thumb" is not satisfying and he looks about for an analytical discussion of the principles governing stability under various conditions. Some of us remember our studies of Weisbach and Rankine, and their theories with that of other investigators is stated in Part I of this book, which, with numerous graphical illustrations and tables, occupies over 40 pages and constitutes the matter of the first three chapters. Chapter IV takes up the subject of Reinforced Concrete and its application to retaining walls, and the following chapters describe various experiments and investigations to fix the matter of pressure, etc., against such walls. Chapter VI and VII, with many excellent illustrations and tables, gives examples of various types and construction of retaining walls and their cost. This part alone would make the book of considerable value to practicing engineers.

Part II considers the matter of Bins which are built to hold material of a more or less granular structure—as coal, ore, sand, grain, etc.—and which may be of metal, wood or concrete. There is an analogy of the forces within a retaining bin and those met with in the case of a retaining wall, that makes this order of sequence a logical one.

In Chapter IX, of some 38 pages, is given an analysis, with diagrams and tables of stresses in various shaped bins and for different materials, that seems to be very complete. The design of bins with constructional details, whether of plate metal, timber or concrete, forms the substance of Chapters XI and XII, while the next chapter considers the subject of costs. The consideration of strength and construction of bins is very properly followed by Chapter XIV on methods of handling materials into and out of the bins. Grain bins are of a specialized type, and the principles which have been laid down relating to design and construction are necessarily somewhat modified to suit the character of the material to be contained and the conditions of use.

Part III of this book relates more particularly to Grain Bins, with Types, in Chapter XV; Stresses, in Chapter XVI; while Chapter XVII records in detail many interesting experiments to determine the pressure of grain in deep bins. The "Design of Grain Bins and Elevators" with examples of construction, introducing many desirable illustrations, constitutes Chapters XVIII and XIX.

Valuable appendices relating to masonry terms and specifications, and to steel structure specifications for material and workmanship, complete this valuable work.

Chemical Reagents; their Purity and Tests: By E. Merck. Authorized translation by Henry Schenck, A. B. (Harvard). D. Van Nostrand Co., New York. Cloth; 6 by 9 ins.; pp. 250, including index. Price $1.50 net.

That eminent chemist, Dr. C. Krauch of Germany, nearly forty years ago found the need of a book on *Chemical Reagents* and began the work of collecting the material for the same. It was his aim to fix uniform standards of purity for the chemicals used in analytical work. It was not until about 20 years ago (in 1888) that this book, "Die Prufung der Chemischen Reagentien auf Reinheit," was published. Three years later a second, revised and enlarged edition appeared, and in 1896 the third and a still further enlarged edition was published. Yet further advances in chemical knowledge, and the practices of the analyst, led Mr. E. Merck to give further revision to the previous works of Dr. Krauch, which book was published in Germany in 1905. This forms the basis of the English translation noted above and which has the sanction and approval of the original author.

The book is well printed with clear topography, on good paper and the arrangement of subjects is such, that the article or reagent under consideration can be readily found and referred to. This makes the book that much more valuable to the student in chemistry, who should be able and willing to test for purity, at frequent intervals, the reagents that are being used.

A more careful following of such practice on the part of the analytical chemists would probably lesssen the wide divergence of results among chemists in their analyses of the same material, which has been too frequently the cause of criticism and disparagement of chemical analyses. W.

Fowler's Mechanical Engineers' Pocket Book, 1908: Edited by William H. Fowler, M. E. Tenth annual edition, revised and enlarged. Scientific Publishing Co., Manchester, Eng. Leather; gilt edges; 4 by 6 ins. Price 2s. 6d.

A copy of a preceding edition of this work was received and placed in the Library of this Society, but this edition has been enlarged and improved, containing some 670 odd pages and an extended index. The subjects are classified, and between each there are a few pages of blank paper for notes by the owner of the book, based on his own experience, etc.

The first section is Miscellaneous Tables and Formulae, such as would naturally be put in such a book as this, intended for ready reference by the Mechanical Engineer..

Then comes a section on Steam Boilers and Fittings, with specifications for materials to be used, including the (English) Board of Trade rules.

A chapter on Types of Boilers, with proportions of parts, etc., is valuable for reference, and also what is noted as Fittings.

A section on Fuels and Combustion follows this, which contains much of value, including as it does tables of calorific power, (C. P.) of various combustibles, and the management of the furnace as an adjunct to the boiler.

Steam Engines is the subject of the next section, with various tables and formulae for the proportioning of parts, etc., and including tables of data of existing engines.

Steam Turbines naturally follows the subject of engines, the various designs of the machines being explained.

Locomotives is the subject of the next section, which contains tables of dimensions as well as sizes of English and American locomotives.

That mystical subject "Entropy" is the subject of the next section of 26 pages, with numerous graphical diagrams and some tables. Then comes a section on Steam Tables, how they are formed, and their use.

Valves and valve gears is the next subject, and occupies some 22 pages, with various cuts, diagrams and tables.

Following the subject of Steam, naturally comes Gas Engines, with diagrams, equations and formulae for proportions, etc.

Gases of various kinds of a combustible character for use in Gas Engines, logically follows in the next section, and Oil Engines—a subdivision of the preceding—follows.

The subject of Hydraulics is of interest to Mechanical Engineers, which includes the subject of pumps, sizes and proportions of parts, etc., with details.

Gearing and Lubrication is an important subject, to which is given 22 pages of valuable data. Following this is a section on ropes and chains, under the heading—Ropes and Hoisting Machinery.

Mining Machinery and Appliances is not overlooked, and then comes the subject of Metallurgy of Iron and Steel, and Strength of Metals and Alloys. There is also a section on Beams and Pillars, and another on Springs, followed by an elementary chapter on Chemistry, and another on Ventilation and Heating.

The book should be of considerable value to engineers and draughtsmen, but will hardly take the place of some of our own American books for use in this country, but it is valuable for reference and comparison. W.

Specifications for Street Roadway Pavements: S. Whinery, M. Am. Soc. C. E. The Engineering News Publishing Co., New York. Pamphlet. 6 by 9 ins.; pp. 56. Price, 50 cents.

The table of Contents gives a good understanding of this valuable book by the author of another desirable book for engineers and municipal officers, "Municipal Public Works" (Macmillan; New York). An Introductory of eight pages is very readable, relating as it does to the value and theory of specifications, that they should be full and complete and be enforced, etc. Then comes specifications more in detail, describing the work, provisions, inspection, general and specific provisions, extra work, preparing the sub-grade, etc.

Foundations follow, of Concrete, Old Paving Stone and of Broken Stone, Bituminious Pavements of the several kinds follows a classification of Asphalt and its alternates—Petroleum Residuum, Sand, Pulverized Stone, etc.; also Asphalt Cement Surface Mixtures, and Base Course, etc., etc. The next sub-division is Granite, Brick and Wood-Block Pavements and a couple of pages of general instructions, including Specifications for Experimental or Untried Pavements, so drawn up as to protect the city and tax payers from extra costs for the benefit of the promoter.

The author has had many years' experience in various lines of engineering work, and in this little book he has laid down rules for the obtaining of good results under a great variety of conditions. It is well worth the price to those concerned in the construction of streets and highways. W.

AMONG THE EXCHANGES.

Putnam's Monthly: In the December, 1906, Journal W. S. E., there is a reading notice of the new periodicals "Putnam's Monthly," published by G. P. Putnam's Sons, New York, N. Y. (this being a revival of the old "Putnam's" which began in 1853, but whose publication was suspended in about 1860 on account of the panic). Mention is made of some of the most important articles that appeared in the first three numbers issued—October, November and December, 1906. The magazine is now just a year old and has been published regularly each month. The high literary character of the earlier articles has been continued throughout the current year, and doubtless the magazine will receive the attention which its merit deserves. A compete file can be seen in the library of this Society.

Besides a large list of engineering periodicals, the library is favored with other well-known literary magazines as, The Outlook, Literary Digest, Scientific American, Open Court, Monist, Journal of Geology, Journal of Sociology (these two being published by the University of Chicago), Popular Science Monthly, Annals American Academy of Social and Political Sciences, Bulletin, American Geographical Society Technical Literature, etc., etc. C.

TRADE PUBLICATIONS.

Structural Steel: Cambria Steel Co., Philadelphia, 1907. Handbook; flexible leather; 4½ by 7 ins.; pp. 468. Price, $1.00.

This is a valuable handbook of information relating to structural steel manufactured by the Cambria Steel Co., containing useful tables, rules, data and formulae for the use of Engineers, Architects, Builders and Mechanics.

Scraper Bucket Excavator: Page & Shnable, Security Bldg., Chicago. Catalogue No. 1; paper 6 by 9 ins., pp. 37; illustrated.

This catalogue describes briefly, with illustrations, a few Page Scraper-Bucket Excavators, as manufactured by Page & Shnable. They are easily handled and experience has shown their adaptability to a variety of work.

SAFETY VALVES: Crosby Steam Gage & Valve Co., Boston. Catalogue; paper; 4½ by 8 ins.; pp. 25; illustrated.

This pamphlet gives "Hints on Safety Valves for Steam Boilers." As manufactured by the Crosby Steam Gage & Valve Co. the valves are divided into two classes: (1) where the valve proper is a disc upon which steam acts when the valve is closed; (2) where the valve proper is a disc provided with an additional area as a part of it, unexposed to the steam when the valve is closed, and acted upon when the valve is open. The following headings may give the reader a fair idea of the contents: Safety Valves; Pop Safety Valves; Ordinary Pop Safety Valves; Regulation of the Lift of the Valve; Annular Pop Safety Valves; Valve Discs and Guides; Protection of Springs and Disc from Steam; Nature of the Helical Spring; Attachment of the Pop Safety Valve to a Steam Boiler, etc.

This publication should be of interest to those connected in any way with steam plants.

ELEVATING, CONVEYING AND POWER TRANSMISSION MACHINERY: Chain Belt Co., Milwaukee. General Catalogue No. 35. Cloth; 6 by 9 ins. pp. 287; fully illustrated and indexed.

The Chain Belt Co. are manufacturers of elevating, conveying and power transmitting machinery for handling packages, cakes of ice. "Chute" boats ashes, hides, railway splice bars, fertilizer, coal, sand, etc., etc. Water elevators for irrigation, drainage and pumping purposes, are also described and illustrated. There are some 20 pages of photographs of plants already installed showing a great variety of applications.

ELEVATING, CONVEYING AND POWER TRANSMISSION MACHINERY: The Jeffery Mfg. Co., Columbus, Ohio. Catalogue 69-A; paper; 6 by 9 ins.; pp. 56; fully illustrated.

This catalogue shows standard and special devices for handling Bone Ash, Coal, Trap Rock, Chemicals, Clays, Coke, Plaster, Slate, Marble, Ores, Quartz, Carbon, Sand, Portland Cement Clinker, etc., etc.

COAL SHOVELS: Sarco Fuel Saving and Engineering Co., New York. Catalogue; paper; 6 by 9 ins., pp. 16; illustrated.

This pamphlet illustrates and describes the Caldwell Automatic Mechanical Coal Shovel manufactured by the Sarco Fuel Saving and Engineering Co.

The first few pages treat of Stoker Failures; Stoker and Grate Separate; Manual Attention; Care of Ashes; Burnouts and Repairs. There is also "A Chapter on Smoke and its Remedy."

REINFORCED CONCRETE: Trussed Concrete Steel Co., Detroit. Two Catalogues; paper; 5 by 8 ins.; fully illustrated.

One of these catalogues, part two, treats of the Kahn System of reinforced concrete as applied to mills and factories. The other, part seven, treats of the same system as applied to bridges and viaducts.

IRON AND STEEL PLATES: Flanged and Pressed Work, etc.—Glasgow Iron Co., Pottstown, Pa. Cloth; 5½ by 7 ins., pp. 91; fully illustrated.

The first twelve pages are devoted to standard specifications of the Association of American Steel Mfrs. with respect to structural steel; following this are forty odd pages with tables of dimensions, weights, etc., of rolled plates, bars, etc., the remainder of the book of flanged press work, etc., such as boiler heads, manholes and covers, lugs, flanges, etc. The illustrations show, by beautiful halftone cuts, these articles in a great variety of form and size.

The book is handsomely printed and is a handy one for the desk of the engineer concerned in the design of boilers, tanks, etc.

DIAMOND CORE DRILL: Sullivan Machinery Co., Railway Exchange, Chicago. Catalogue No. 55; paper; 6 by 9 ins.; pp. 157; illustrated.

Many drills for different classes of work are described and illustrated. The introduction calls attention to the fact that in this volume two objects have been kept in view: First, to give a proper idea of the theoretical and practical advantages of prospecting mineral lands with the diamond core drill; and second, to gather under one cover all the information necessary to the selection of a suitable drilling outfit, its purchase, use and maintenance.

ROCKWELL APPLIANCES: Rockwell Engineering Co., New York. Pamphlets. 6 by 9 ins.

Six little pamphlets have been received from the Rockwell Co., devoted to the following subjects: Fuel Oil Burning Appliances; Heating Machines for annealing, hardening, tempering, coloring, etc.; Brazing Furnaces; Flue Welding Furnaces; Rivet Heating Furnaces; Pot Furnaces for lead and cyanide hardening and for melting soft metals: and Double Chamber Metal Melting Furnaces, for copper, brass, bronze, aluminum, iron and steel, etc.

COAL CRUSHERS: The Williams Patent Crusher and Pulverizer Co., St. Louis, Mo. Also 545 Old Colony Bldg., Chicago. Catalogue; paper; 6½ by 9 ins.; pp. 58; illustrated.

The first thirty pages are given to description and illustration of the Williams Coal Crusher; following this, there are some twenty pages of coal crusher testimonials, a list of patents, etc. This catalogue bears the date of 1906. The 1904 catalogue refers to crushers and pulverizers for a number of different purposes, such as ore, stone, bone, clay, etc.

"COALING IN A SEAWAY:" Lidgerwood Mfg. Co., New York, 1907. Catalogue; stiff paper cover 8½ x 11 ins.; pp. 48; handsomely illustrated.

This pamphlet contains numerous illustrations, from photographs, of the "Lidgerwood-Miller Marine Cableway" method of coaling at sea. The coal is transported from one boat to another in bags by means of a Main Cable, a Tensioning Device, a Load Carriage, Traversing Ropes, Two Ships Winches, and Lowering and Controlling Devices. This apparatus "is the outcome of nine years' development through the experience gained by the seat trials of the United States Navy, the British Admiralty, the Russian Admiralty and the Royal Italian navy."

"NAVY BULLETIN, NO. 22:" Cutler-Hammer Mfg. Co., Milwaukee. 1907. Catalogue; paper; 5 x 8 ins.; pp. 48; illustrated.

This little booklet is designed for use of those selling electric motors or motor-driven machinery to the Navy Department, and contains full descriptions, illustrations, dimension diagrams and shipping weights on starting panels, speed regulating panels, machine tool controllers, resistances, circuit breaker panels, etc. It also explains how to select the proper piece of apparatus in each case.

DICTIONARY OF ELECTRIC RAILWAY MATERIAL: Street Railway Journal, New York. Pamphlet, 6 x 9 ins.; pp. 169, including index.

This Dictionary, dated 1907, is the third annual edition, and is a handy guide for buyers of electric railway equipment and supplies. It contains brief descriptions of a large number of the principal types of apparatus and supplies manufactured in the United States and information regarding leading dealers, engineers, contractors, financial institutions, etc., doing business with street and interurban railway companies. There are three main divisions under the headings, "Manufacturers," "Dealers," and "Financial, Professional, etc."

VALVES AND FITTINGS FOR AMMONIA: Crane Company, Chicago. 1907. Catalogue. Flexible leather; 4 x 6¾ in.; pp. 125; including index; many illustrations.

The Crane Co. states that the valves and fittings illustrated in this catalogue (with the exception of malleable iron screw fittings) are an entirely new line and were designed in accordance with the most approved engineering practic as to standards, interchangeability of parts, proportions, thickness of metal, etc., no attempt being made to utilize old patterns and tools.

A large number of tables of weights, dimensions, etc., are to be found in this little booklet.

WIRELESS CLUSTERS AND LIGHTING SPECIALTIES: Benjamin Electric Mfg. Co., 42 W. Jackson Blvd., Chicago. Bulletin; paper; 6 by 9 ins.; pp. 8; illustrated.

The Benjamin Electric Mfg. Co. has just issued, under date of October, a Supplementary Bulletin containing additions and changes affecting Catalogue B-17 and B-17a, and a number of new devices are listed, which will doubtless meet with the approval of the trade. Copies of this Bulletin will be supplied on application.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for August, 1907, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

John Brunner, M. W. S. E., Chicago. National Geographic Magazine, June, July and August, 1907. Pams.

Report of the Rocky Mountain Park of Canada, Dept. of Int., Dominion of Canada. Pam.

A. Elliott Kimberly, Asst. Engr., State Board of Health, Columbus, Ohio. "The Use and the Abuse of Sewage Purification Plants." Pam.

New Jersey State Board of Health. 30th Annual Report, 1906. Cloth.

O. Chanute, M. W. S. E., Chicago. American Magazine of Aeronautics, Aug., 1907. Memorial of Samuel P. Langley, Secy. Smithsonian Institution, 1887-1906. Pams.

E. L. Corthell, M. W. S. E., New York. "Port of Para," Brazil, by Elmer E. Corthell. Pam.

National Brake and Electric Co., Milwaukee, Wis. "National Air Brakes," Manual of Installation and Maintenance. Cloth.

Hiram A. Miller, M. W. S. E., Boston. 4th Annual Report of the Charles River Basin Commission, 1906. Pam.

National Board of Fire Underwriters, Chicago. "National Electrical Code," 1907. Pam.

John Wiley & Sons, New York. "Shaft-Sinking Under Difficult Conditions," by J. Riemer; translated by C. R. Corning. Cloth.

Michigan State Board of Health. 33d Annual Report of the Secretary, 1905.

E. E. R. Tratman, M. W. S. E., Chicago. "Annual Report of the Imperial Railway Bureau," 1905-1906. Tokyo. Pam.

"Guide du Monteur," by Jules Merlot, 1907. Cloth.

Bi-monthly Bulletin; American Institute of Mining Engineers, Novembers, 1906. Pam.

Engineers' Club of Philadelphia—List of Members, 1907. Cloth.

"The birthplace of the Turret," Pallion Shipyard, Sunderland.

Proc. 4th Annual Meeting, Assn. of Transportation and Car Accounting Officers, 1907. Pam.

Report of Chief Commissioner of New South Wales—Government Railways and Tramways, 1907. Pam.

Spec. for building single-screw steel derelict destroyers for the U. S. Revenue-Cutter service. "Revenue-Cutter No. 17," Washington, 1907. Bds.

Spec. for triple-expansion, single-screw propelling engine, with boiler and auxiliary machinery, for Revenue-Cutter No. 17 (for service as a derelict destroyer), Treasury Dept., Washington, 1907. Bds.

Water Supply and Irrigation Papers. Nos. 195, 197, 199, 201, 203, 204, 205, 206, 208. Pams.

Bul. International Ry. of Congress Assn. (English Edition), Jan., Feb. and March. Nos. 1, 2 and 3. 3 Pams.

Ry. Signal Assn., Proc. of; Nos. 3 and 4, 1907. 2 Pams.

Administration Report on the Rys. in India for 1906, by Railway Board. Pam.

State of Rhode Island and Providence Plantations. Annual Report of Commissioner of Dams and Reservoirs. Jan., 1907. Pam.

Board of Water Supply, New York City. Spec. and Drawings for main Dams for the Ashokan Reservoir near Brown's Sta. in towns of Olive and Marbletown, N. Y. Pams.

D. Van Nostrand Co., New York. "Chemical Reagents; their purity and tests," by Merck, 1907. Cloth.

New York State Engineer and Surveyor. Annual Report, 1905. 3 bd. Vols.

Otis F. Clapp, City Engineer, Providence, R. I. Annual Report, 1907. Pam.

City of Chicago. Statistics, Jan.-June, 1907, Vol. VII, Nos. 1 and 2. Pam.

J. H. Warder, Secy., W. S. E., Chicago. 12 bound volumes.

"A Handbook of Engineering Laboratory Practice," Smart, 1898.
"A Treatise on the Metallurgy of Iron," Bauerman, 1868.
"Sewer Design," Ogden, 1899.
"Principles of Dynamo Electric Machines," Hering.
"The Calorific Power of Fuels," Poole, 1901.
"Sewerage," Folwell, 1898.
"Steam Boiler Economy," Kent, 1901.
"A Treatise on Surveying," Alsop, 1865.
"Practical Application of Slide Valve and Link Motion," Auchincloss, 1869.
"Street Pavements and Paving Materials," Tillson, 1900.
"Water Supply Engineering," Folwell, 1900.
"Hydraulic Cement," Spalding, 1898.

Illinois Board of Charities, Springfield, Ill. Quarterly Bulletin, July, 1907.

N. Y. City Board of Water Supply. "Contract No. 4," for construction of Field Office Bldg for Division and Section Engineers, Peekskill Division, Catskill Aqueduct, Cortlandt, N. Y., with drawings, 1907.

"Contract No. 5," for construction of a portion of an Intercepting Sewer in Kingston, N. Y. 1907, with drawings. 4 Pams.

O. H. Basquin, M. W. S. E., Evanston, Ill. "Stresses in Simple Columns under Eccentric Load," April, 1907. 2 Pams.

Michigan College of Mines, Houghton. Year Book, 1906-7. Pam.

Ohio Bureau of Inspection and Supervision of Public Offices. "Comparative Statistics, Cities of Ohio," 1905-6. 2 Pams.

Ald. Linn H. Young, Chicago. "Report of Committee on Gas, Oil and Electric Light to the City Council, on Telephone Service and Rates," Chicago, 1907. Pam.

Howard C. Ives, Worcester Polytechnic Institute, Worcester, Mass. "Switches and Turnouts," by H. C. Ives. Reprint from Journal Worcester Polytechnic Institute, March, May and July, 1907.

American Steel and Wire Co., Chicago. "Engineers' Handbook of Concrete Reinforcement," July, 1907. Cloth.

H. H. Costey, Jr., M. W. S. E., Chicago. Cambria Steel Co. "Handbook of Structural Steel," 1907. Morocco.

Iowa Board of R. R. Commissioners. 29th Annual Report, 1906. Cloth.

Indiana Dept. of Geology and Natural Resources. 31st Annual Report, 1906. Cloth.

Scientific Publishing Co., Manchester, England. "Steam Boilers and Supplementary Appliances," by W. H. Fowler. Cloth.

Dr. W. Michaelis, Jr., M. W. S. E., Chicago. "The Hardening Process of Hydraulic Cements," by Dr. W. Michaelis, Sr. Pam

Chas. J. Poetsch. M. W. S. E., Milwaukee. Annual Report, Board of Public Works, 1906. Pam.

McGraw Publishing Co., New York. "Street Railway Journal's Dictionary of Electric Railway Material." 1907. Pam.

American Public Works Assn. 2d Convention, Atlanta, Ga. Sept. 14th and 15th, 1906. Cloth.

City Statician, Chicago. 29th, 30th and 31st Annual Reports. Dept. of Public Works, for the years 1904, 1905 and 1906. 3 Vols. Cloth.

EXCHANGES.

University of Michigan, Ann Arbor, Mich. "The Michigan Technic," June, 1907. Pam.

National Fire Protection Assn., Chicago. Quarterly Bulletin, July, 1907. Membership Directory, 1907. Pams.

American Institute of Architects, Washington, D. C. Proc. of the 40th Annual Convention, 1906. Pam.

Western Railway Club, Chicago. Official Proc. for the year 1906-7. Cloth

Missouri Bureau of Geology and Mines, Jefferson City, Mo. "Public Roads, their improvement and maintenance." Vol. V—2d series. Cloth.

Institution of Electrical Engineers, London, England. Proc., April 25th and May 2d, 1907. Pam.

American Institute of Mining Engineers, New York. Transactions, containing papers and discussions of 1906. Vol. 37.

Institution of Mechanical Engineers, London. Proc. Jan.-March, 1907. Pam.

National Assn. Cotton Manufacturers. Trans. April, 1907. Bds.

Liverpool Engineering Society. Trans. 1906-7. Pam.

American Mining Congress, Denver. Trans. 9th Annual session. 1906. Pam.

American Ry. Engr'g & M. of W. Assn. Bulletins No. 89 and 90, 1907. Pams.

Canadian Society of Civil Engineers. Trans. Jan.-June, 1906. Part I, and Oct.-Dec., 1906, Part II. Vol. XX.
Report of Annual Meeting, 1907. Vol. XXI. Pams.

Engineers' Society of Western Pennsylvania. Charter, By-laws and Membership List, July, 1907. Pam.

Engineers' Club of St. Louis, Mo. 12th Annual Bulletin, List of Members, etc., 1907. Pam.

American Ry. Master Mechanics' Assn. Report of Proc. 40th Annual Convention, 1907. Leather.

Ontario Bureau of Mines, Toronto. Reports of Bureau, Vol. XIV, 1905; Vol. XV, 1906. 2 Vols. Cloth.

Illinois State Geological Survey. Bulletin No. 4. Year Book for 1906. Cloth also paper.

Institution of Naval Architects. Transactions, List of Members, etc., for 1907. Cloth.

Institution of Electrical Engineers, London. Proceedings. May, 1907
List of Officers and Members; Articles of Assn., etc., 1907
Index to Vol. 39 of Proceedings.
List of Accessions to Library from April 1st to September 14th, 1907. 4 Pams.

GOVERNMENT PUBLICATIONS.

U. S. Geol. Survey, Dept. of Interior.
"Production of Bauxite and Aluminum in 1906," by E. F. Burchard. Pam.
"Production of Barytes in 1906," by E. F. Burchard. Pam.
"Production of Asbestos in 1906," by Diller. Pam.
"Production of Monazite and Zircon in 1906." Pam
"Production of Mica in 1906." Pam.
"Production of Flourspar and Cryolite in 1906." Pam.
"Production of Anthracite Coal in 1906." Pam.
"Production of Asphalt and Bituminious Rock in 1906." Pam.

"Production of Phosphate Rock and Phosphorus in 1906." Pam.
"Production of Quartz (flint) and Feldspar in 1906." Pam.
"Production of Precious Stones in 1906," by Sterrett. Pam.
"Production of Glass-sand, Sand and Gravel in 1906," by Burchard. Pam.
"Production of Chromite or Chromic Iron Ore in 1906." Pam.
"Production of Mineral Waters in 1906," by Sanford Pam.
"Production of Nickel, Cobalt, Tungsten, Vanadium, Molybdenum, and Tantalum in 1906." Pam.
"Production of Salt and Bromine in 1906," by A. T. Coons. Pam.
"Production of Slate in 1906," by A. T. Coons. Pam.
"Production of Tin in 1906," by F. L. Hess. Pam.
Gypsum and Gypsum Products in 1906.
The Cement Industry in the U. S. in 1906, by Eckel.
The Stone Industry in 1906, by A. T. Coons. Pam.

U. S. Dept. of Agriculture, Forest Service.
Cir. 70, Effects of Moisture upon the Strength and Stiffness of Wood, by Tiemann.
Cir. 105, White Oak in the Southern Appalachians. July, 1907.
Cir. 108, The Strength of Wood as influenced by Moisture, by Tiemann. Pam.
Cir. 109, Forest Planting in the North Platte and South Platte Valleys. Pam.
Cirs. 113 and 116. "Use of Dead Timber in the National Forests" and "The Waning Hardwood Supply and the Appalachian Forests," by W. L. Hall. Pams.
Exports and Imports of forest products, 1906, by R. S. Kellogg.
Silvical Leaflets. Nos. 1 to 14 inch. 4 Pams.

J. R. Mann, M. C., Washington, D. C. Yearbook—Dept. of Agriculture, 1906.

Supt. of Documents, G P. O. Catalogue of U. S. Public Documents, July, August, and September, 1907.

U. S. Dept. of Commerce and Labor, Bureau of Census. Census of Manufacturers, 1905.
Bul. 75, Agricultural Implements. Pam.
Bul. 78, Iron, Steel, Tin and Terne Plate. Pam.
Bul. 79 Printing and Publishing. Pam.
Bul. 80, Paper and Wood Pulp. Pam.

U. S. War Dept.
Annual Report of Secretary of War, Chief of Staff and others, 1906. Vol. I. Cloth.
Annual Report Quartermaster-General, fiscal year. June 30th, 1906. Vol. II. Cloth.
Annual Report Division and Dept. Managers, fiscal year June 30th, 1906. Vol. III. Cloth.
Annual Report Militia Affairs; Military Schools and Colleges, fiscal year. June 30th, 1906. Vol. IV. Cloth.
Annual Report of the Chief Engineers, fiscal year June 30th, 1906. Vol. V. Cloth.
Annual Report of the Chief of Ordinance. Vol. VI. Pam.
Annual Report Philippine Commission, Part I. Vol. VII. Cloth.
Annual Report Philippine Commission, Part II. Vol. VIII. Cloth.
Annual Report Philippine Commission, Part III. Vol. IX. Cloth.
Annual Report Acts of the Philippine Commission Nos. 1408, 1538 and Public Resolutions, etc., from Oct., 19th, 1905 to Sept. 15th, 1906. Cloth.

U. S. Commissioner of Labor, Washington. 21st Annual Report, 1906, Strikes and Lockouts. Cloth.

U. S. Reclamation Service, Dept. of Interior. Spec. 148, Lower Yellowstone Project, North Dakota-Montana. Highway Bridges. Sept., 1907.

BOOKS PURCHASED.

McGraw Publishing Co., New York. 8 Vols. Cloth.
- Iron, Steel and other Alloys, H. M. Howe, 1906.
- Report of Electric Railway Test Commission, to the President of the Louisiana Purchase Exposition, 1906.
- American Electric Railway Practice, by Herrick and Boynton, 1907.
- Practical Illumination, by Cravath and Lansingh, 1907.
- Some Details of Water-Works Construction, by Wm. R. Billings, 1898.
- Electric Railways: Collection of papers presented at International Electrical Congress, in St. Louis, 1904.
- Index to the Electrical World, 1883-1896.
- Proc. International Electrical Congress held in Chicago August, 1893.

Louisiana Purchase Exposition Co., St. Louis. 8 Vols. Cloth.
- International Congress of Arts and Science, 1906.

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METHODS OF PUMPING DEEP GROUND WATERS.

By Charles B. Burdick, M.W.S.E.

Presented June 5, 1907.

With growing intelligence in sanitary matters, pure water supplies are becoming of greater importance. Among our supplies none, from a hygienic standpoint, is more important than that from deep wells.

It is the object of this paper to review, as briefly as is consistent with a good understanding of them, the means now in use for pumping these deep ground waters; their applicability and their economy; referring particularly to those supplies considerably below suction depth.

THE PRINCIPLES OF WELL FLOW.

For added clearness in the subsequent discussion let us briefly review the general principles of well flow. This principle is the same whatever the character of the well—whether it flows by "gravity" or whether the water stands at a great depth below the ground surface; whether a tubular well; or whether a masonry curbed well of large diameter. The removal of water tends to lower the water surface within the well. This lowering of the water surface disturbs the equilibrium between well water and ground water, and flow takes place from ground to well. This flow is induced by the difference in head between the water in the well and the water in the ground. As before beginning the operation of pumping the well, the ground water rests in a state of equilibrium, the head which induces flow to the well is measured by the "drop" in the well water surface incident to pumping. This drop actually exists on the removal of water from an open well. The same effect is produced by "suction" in tubular wells, or by the action of compressed air in the operation of the air lift. The flow to the well is a function of this difference in pressure or "drop." The amount of the drop bears a fixed relation to the flow once uniform conditions are established. The energy induced by this drop is consumed in imparting velocity to the water and in overcoming friction between ground and ground water in its passage to the well. In sand wells the well strainer offers further resistance, and if the well is deep or the flow large, compared to the well diameter, the friction of the rising water in the well bore must be considered. In a large majority of cases the friction of the ground water is the important source of loss, the other factors being of significance only in special cases.

As is well known, the resistance to flow in conduits or channels varies as the square of the velocity. It has been demonstrated by experiment that this law does not hold in the flow of water through porous material, such as sand, gravel, silt and the like, where the water must pass through minute interstices. It has been demonstrated that in such cases the resistance is a direct function of the velocity. These laws are of importance in forecasting the yield of wells. The feed to the well may approach the case of one or more

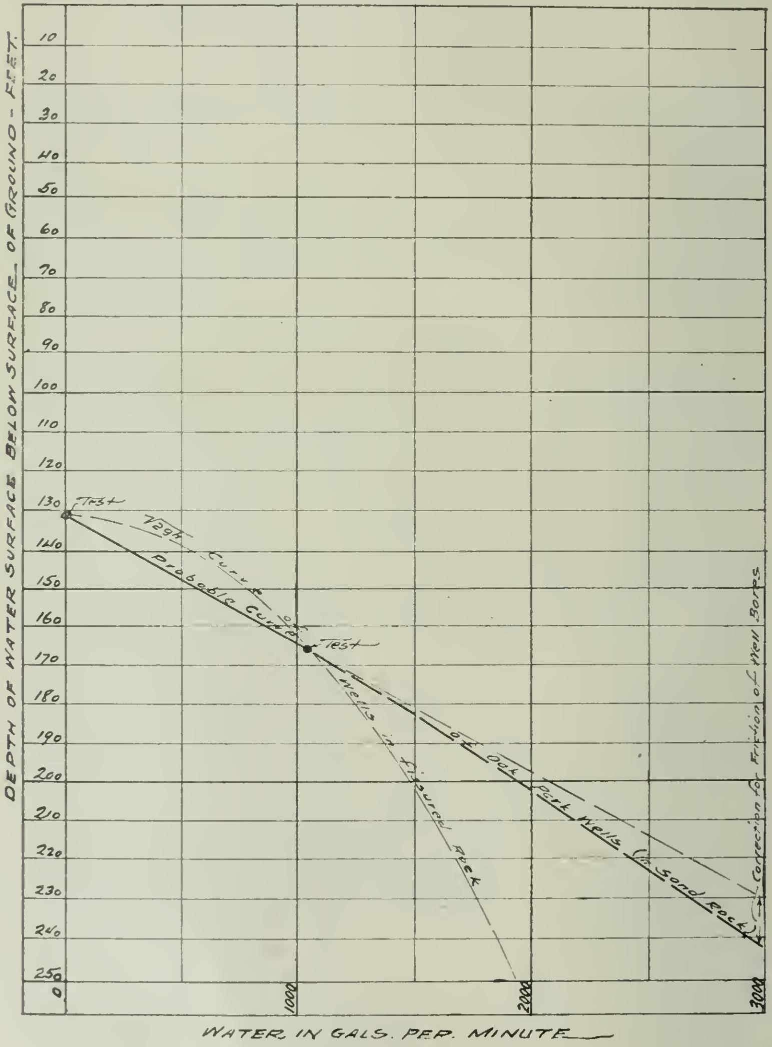

FIG. 1.—Typical Well Flow Curve

underground conduits; this is true in certain wells in limestone where the solvent action of the water has caused passages of considerable dimensions to be formed. Such a condition would result in a flow curve, as shown in Fig. 1, by the curved line; where the flow varies as the square root of the "drop" induced by pumping. The more common case, however, is represented by the nearly straight line in the same illustration when the water passes to the well through minute interstices in the sands, gravels, sand rocks and

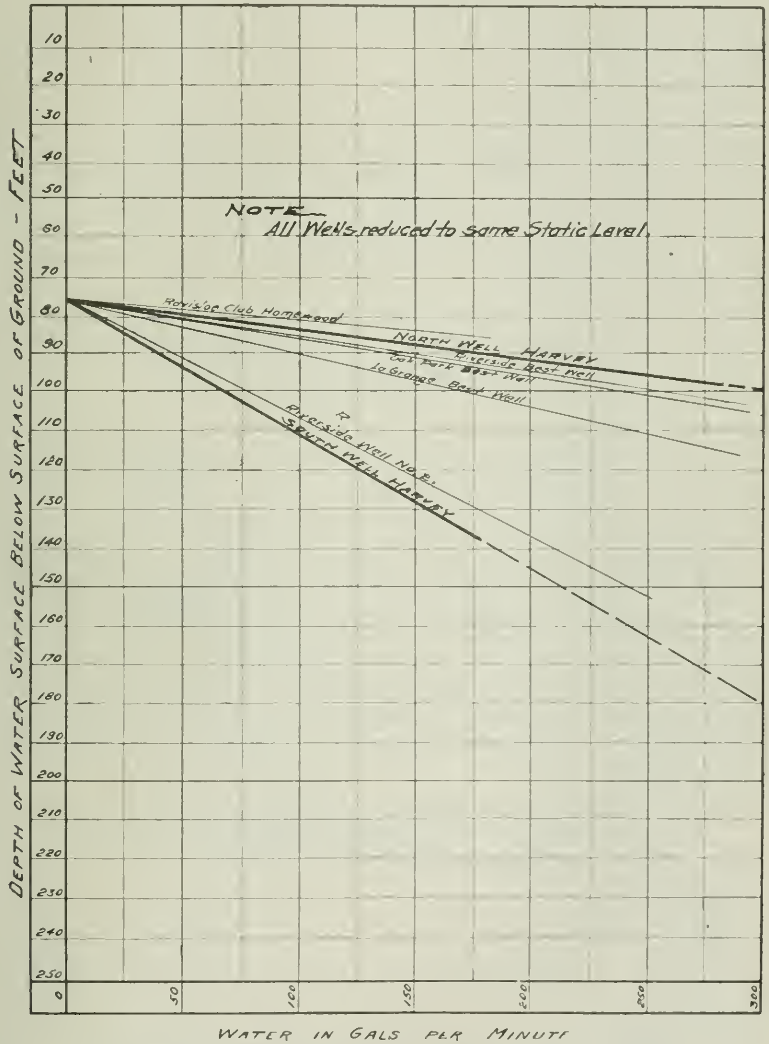

FIG. 2.—Sundry Well Flow Curves in Neighborhood of Chicago.

even most limestones. In this case neglecting the well tube friction, the yield of the well is directly proportional to the "drop."

In forecasting the possibilities of a ground water supply from tests of existing wells it is important to fix the flow curve. If the curve takes the form of a straight line, as is usually the case, the location of two points will fix it. If there is any doubt as to the form of the curve, several points as widely distributed as possible should be located. The static water level is, of course, the origin of the flow curve. In predicating future possibilities, and indeed in designing the machinery, account should be taken of possible future changes in the location of this plane. This has been the stumbling block of many failures.

Under a set of fixed conditions the plane will remain fixed. In deep wells of large tributary water-shed, such as those in the Potsdam or St. Peter's sandstones which supply the greater part of the deep well water in northern Illinois and southern Wisconsin, the static water levels are probably unaffected except by pumping; the time of passage from source to well being so slow that seasonal conditions are without effect. The history of the static water levels in this vicinity is instructive.

In the early eighties, when water works construction commenced upon a large scale, the underlying sand stones when penetrated, usually furnished flowing wells. In some cases the heads were sufficient to lift the water, within a vertical pipe, thirty or forty feet above the ground surface. Several wells, of 10 in. to 12 in. diameter at the top, flowed at the rate of one million gallons or more per 24 hours at the ground level. With the constantly increasing number of wells drilled all over this territory, and with the increased demand for water, due to the growth of cities, such a quantity of water was drawn from these sand-stones as to produce an underground current sufficient to use up an increasing quantity of head. As a result, the flow of the wells diminished, and when pushed the hardest, ceased to flow, necessitating changes in the pumping devices. Further pumping still further lowered the static levels, and a number of cases exist where wells once flowing at the surface, have in the course of twenty years or less receded from 100 to 150 feet. Table No. 1 shows the experience of several cities in this respect:

TABLE NO. 1, SHOWING GENERAL RECESSION OF STATIC GROUND WATER PLANES. ALL ELEVATIONS REFER TO SURFACE OF GROUND AT PLACES NAMED.

La Grange, Ill.	
1889	—5
1893	—18
1900	—26
1905	—26
Oak Park, Ill.	
About 1890	0
1905	—100 to —140

Harvey, Ill.	
1898	—23
1901	—30
1905	—70
Dubuque, Ia.	
1899	+35
1906	+15

WATER LEVEL GAUGE.

Often one of the most troublesome observations in the testing of deep wells is the measurement of the lift when the pump is operating. An observation of the water level when the pump is shut down will not suffice, as in operation the water level may fall away in very considerable amount. There has elsewhere been described an electric device depending upon an insulated wire dropped into the well which closes a circuit with the well casing when the water level is touched. This is only applicable, however, where there is sufficient space between the casing and water pipe, which is often not available, and at best the device gives some trouble.

There is another device for this purpose which has been used in this vicinity for ten years or more, and which it is believed has not

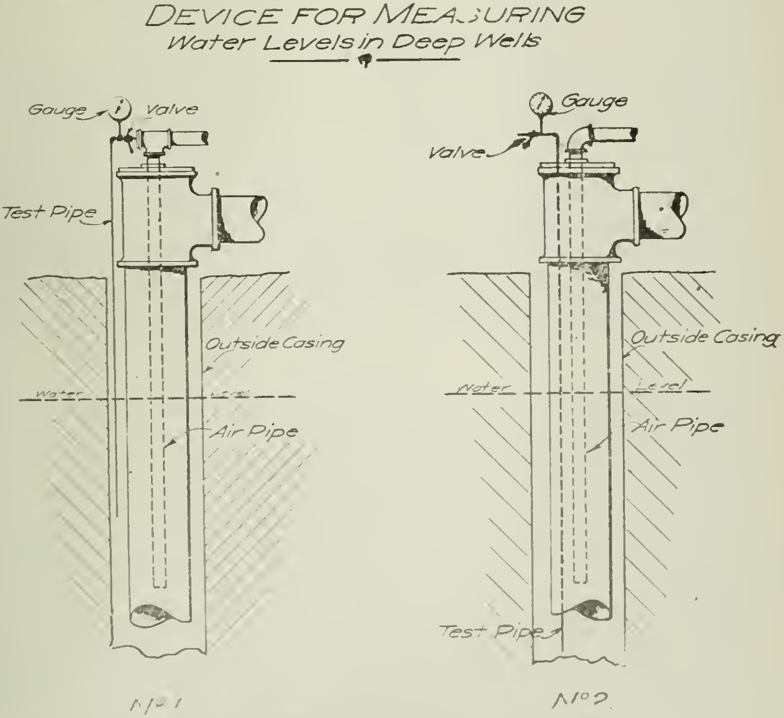

FIG. 3.—To Measure the Water Levels in Wells.

been described in print. Fig. 3 shows the device coupled to an air lift pump. It consists of a small pipe (¼ in. will do), a valve and a pressure gauge so graduated that it can be easily read to one pound or less. A known length of pipe is dropped into the well; air pressure is then applied until all the water is driven from the pipe, as evidenced by the refusal of the gauge to rise further. This pressure reduced to feet shows the amount that the end of the pipe is submerged.

In No. 1 (Fig. 3) is shown an application to a case where the exterior of the water pipe is accessible. Upon an air lift when this can be done the compressed air can be obtained by tapping the air pipe. No. 2 shows an application to an air lift where there is no room outside of the eduction or water pipe, and with this arrangement a hand air pump is desirable as the pressure required in the test pipe is a little in excess of that in the air pipe. The ordinary beer pump or large bicycle air pump answers this purpose nicely. Applied in this way the lift can be measured readily, even when the well casing is used as a discharge pipe.

In operation there are a number of precautions to be observed. The pipe must, of course, be unobstructed and should be tight. Upon a rising water level the water must be blown out before each reading.

THE RECIPROCATING PUMP.

The most obvious means of reaching well water that has receded below suction limit is to depress the pump barrel or cylinder to such depth that it can reach the water. This is the principle of the ordinary farm yard pump. The device, essentially, consists of pump barrel, plunger and valves and a set of jointed rods for transmitting power from the surface to the pump plunger within the well.

The pump barrel, commonly of brass, is usually attached to the bottom of the pump discharge pipe, within which the rods move up and down through a suitable stuffing box at the top, and through which the plunger discharges its load through a proper valve. In certain cases the pump barrel is fastened to the well casing by an annular wedge or "packer," and the well casing itself forms the discharge pipe.

The plunger may be single or double acting, or two plungers may be employed, one working above the other. The valves are usually of the ball type, although poppet valves are used.

The source of power may be as desired; steam may be applied directly to the rod through a direct acting steam head. A special steam head is made which operates double plungers, the rods being accommodated one within the other, and power heads are made producing the same effect.

Where the quantity of water is small and the lift moderate this machine operates with good results, but where considerable water is handled, especially at high lifts, it has proved both costly of operation and maintenance. With the single acting plunger the water column must be started and stopped once in each revolution, and twice with the double acting plunger; this operation, particularly at high piston speed, is both extravagant of power and hard on the machinery. This difficulty has been partially overcome by the use of the differential plunger whereby the rising water column is only partially brought to rest.

Under the higher lifts, the slower the plunger speed, the more satisfactory the operation; for the higher lifts 80 to 100 feet piston speed is the limit, while small quantities can be raised 30 to 50 feet with plunger speeds as high as 120 to 130 feet per minute, without serious wear and tear.

In Table No. II is shown abstracts of three tests upon E. E. Johnson's deep well pump, an account of which was read by the designer before this Society in 1897, and from which paper the data is taken. These efficiencies probably represent the best that we can hope for by reciprocating machinery under the lifts named:

TABLE No. II. DEEP WELLS. ABSTRACT OF TESTS ON JOHNSON DEEP WELL PUMPS.

	Stockton, Ill.	Ames, Iowa.	Cambridge, Ill.
1. Pump lift feet..........	274½	390	252
2. Actual water, gal. per min.	120.97	133.	71.82
3. Slip of valves %........	+1.9%	+3.8%	—3.3%
4. Av. Pump Speed, r. p. m ...	25.59	27.14	11.62
5. Cylinder diameter	5¾ in.	5¾ in.	6¾ in.
6. Pump stroke per rev.....	41.25 in.	42.0 in.	41.25 in.
7. Efficiency pump	72%	......	67%
8. Efficiency, pump and eng.	63%	......	36.5%
9. Steam duty, mil. ft. lbs...	....	45.5	....

Under lifts of about 50 feet or less the single acting plunger of small pumps will approach this efficiency, but falls off rapidly with increasing depth. The motive power for machines of this type may be so selected as to give any duty desirable within the limitations of the pump efficiency.

THE AIR LIFT.

The air lift as a pumping device was probably first used, at least experimentally, as early as 1797. In America patents were issued to Capt. James B. Eads in 1870, Joseph P. Frizell in 1880 and Dr. Pohle in 1892. The device did not attain commercial importance until the investigations of Dr. Pohle became publicly known, shortly before his patent was granted. The general principle of this device will be seen from a glance at Fig. 4. Compressed air through a small pipe is forced into the well and released in the bottom of an open pipe, as shown, resulting in a discharge of air and water. The mechanics of this appliance seem at first glance somewhat mysterious, and indeed the first application for patent was refused upon the ground that the method of operation claimed, was contrary to a well established physical law. As clear an explanation as the writer

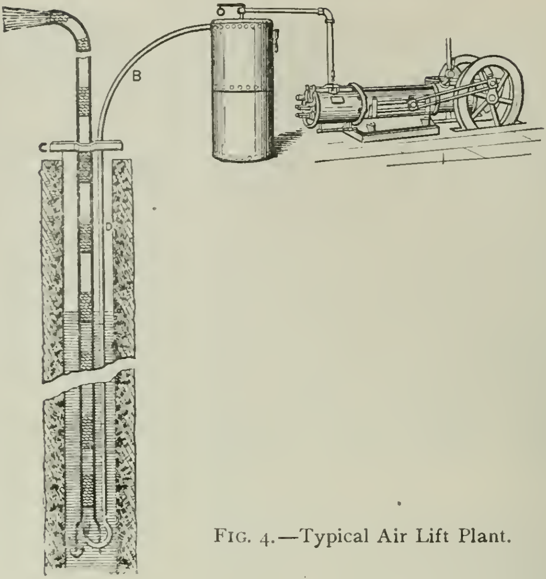

Fig. 4.—Typical Air Lift Plant.

has seen, was published in the Engineering News of June 8, 1903, together with some history of the device.

Mr. Frizell's patent states that the air is mixed with the water in the form of minute bubbles. Dr. Pohle's patent specifies the formation of "piston like" layers of air and water. In a catalog recently issued by one of the companies dealing in this machinery, and abstracted in the Engineering Record of Dec. 5, 1905, great stress is laid on the formation of these "piston like" layers, if best efficiency is to be secured; but the catalog naively harmonizes this theory and observation by stating that "it is likely that before they reach the surface there is a general breaking up." No means are provided for forming these layers other than proportioning the supply of air to the water delivery.

The application of the air lift is properly divided into two parts, namely, the generation of the compressed air, and its use in pumping. It is most useful to consider these parts separately in order that the pump may be compared with other means of lifting water.

In the following data regarding efficiency, it has been the effort to separate, in so far as possible, the efficiency of the pump itself and the "over all" efficiency of the plant, including the compressor. The latter, of course, may vary widely in its economy.

Several methods of applying the air and arranging the pipes in the well are shown in Fig. 5. These methods are further modified by the manner of releasing the air from the bottom of the air pipe. At various times especial advantages have been claimed for a special form of nozzle. These have been of almost every conceivable form, including a perforated head, a perforated or stotted pipe, a contract-

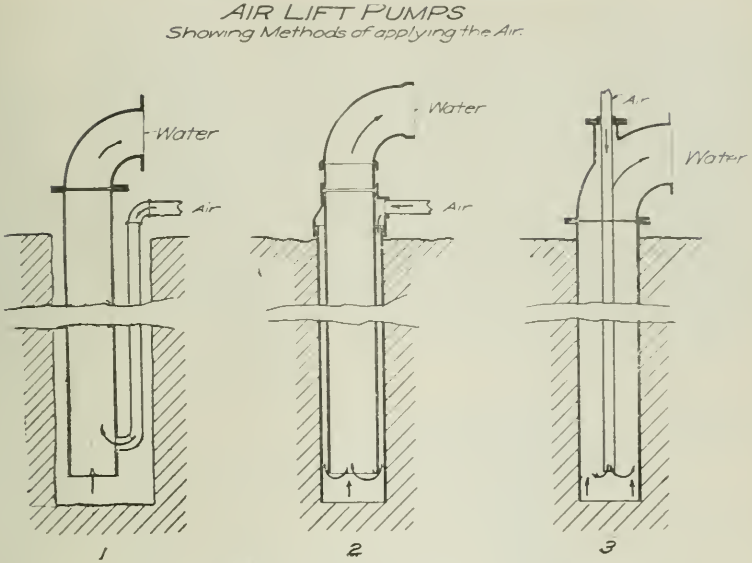

FIG. 5.—Methods of Supplying Compressed Air.

ed nozzle turned upward or downward, or an open end pipe arranged in the same way. At the present time probably a majority of the applications of compressed air are made through the end of an open pipe pointing downward, and experience seems to show that this application is fully as efficient as any other.

The depth to which the air pipe is submerged, and the consequent pressure of the air, undoubtedly has an important bearing upon efficiency. It is usual to express this submergence as the ratio of that portion of the mixed air and water column submerged in the water of the well, to the total height of the same column, measured from point of air application to the point of delivery of the air and water mixture.

Experiment and experience seems to show that the best results are obtained under a submersion of about 66 %, and that at least under lifts of 50 ft. or less the efficiency is reduced about one-half when the submersion is reduced to 33 %. Manufacturers claim to have plants under special conditions working satisfactorily under submergences as low as 30 % and as high as 75 %. They usually recommend about 60 %. The most favorable air pressure but slightly exceeds the head of water due to submergence, and the air pipes and passages should be so proportioned as to permit passing the proper quantity of air without seriously reducing its pressure.

The size of "eduction pipe" through which the column of mixed air and water rises should bear a reasonable relation to the quantity of water delivered, as there is evidently a relation where practically no work will be accomplished. There appears to be some latitude, however, in this matter. In the experiments of Browne and Behr, hereinafter referred to, the best efficiencies were obtained with eduction pipe velocities of 4 to 5 ft. per sec., neglecting the volume of the air in suspension. It should be said, however, that no higher velocities were apparently used, and that their device was operated at velocities as low as 1 ft. per sec. Judging from recent practice a velocity of 4 ft. per sec. is desirable under usual conditions.

In regard to air consumption Prof. D. W. Mead in Turneure's and Russell's *"Public Water Supplies,"* says: "For reasonable efficiency the submergency of the discharge pipe should be at least 60% of its total height" and "The formula commonly used for determining the relation of the various factors in the air lift problem is:

$$q = \frac{125\ A}{h}$$

"in which q = gallons of water per min.
A = cu. ft. of free air per min.
h = height of lift in feet from water surface to point of discharge."

This formula transposed in terms of air reads:

$$A = \frac{q\ h}{125}$$

The formula, therefore, taken in connection with a fixed submergence ratio sets a value upon the possible efficiency; and inasmuch as the volume of free air required varies directly as the lift and, submergence ratio remaining constant, the air pressure also varies as the lift, the efficiency must necessarily be greater at low lifts than high. Assigning values to this formula in accordance with 60% submersion shows efficiencies as follows:

Lift.	$\text{Efficiency} = \frac{\text{H. P. Water Lifted}}{\text{H. P. Receiver Air}}$
25′	66%
50′	42%
100′	29%
150′	24%

This formula approximately expresses the relation of the factors in the most efficient plant with which the writer is personally acquainted, under the lift at which it is operated.

The efficiency of the air lift pump has been fruitful of much discussion, and various results have been claimed for it, differing widely in themselves. The subject has been more fruitful of theoretical computations than results from plants actually in operation, although the number of these plants is very large. The reason for this is probably to be found in the difficulty of making accurate tests, coupled with a quite general lack of knowledge of the governing principles, upon the part of operatives who have the opportunities for testing. Much is seen in print of cases where in this plant or that, the air lift has saved (or wasted) "so much" fuel as compared with the plant formerly used, but very few statements are to be found sufficiently exact to warrant an intelligent opinion. Much copying of careless statements is to be found in books upon compressed air.

Mr. E. E. Johnson, in closing the discussion upon his paper presented before this Society in 1897, places the maximum limiting efficiency of the air lift as a pump, upon the ratio of the theoretical power to deliver the water, to the least power to compress the necessary air isothermally; upon the assumption that the submersion is such that the air pressure is equal to the hydrostatic pressure due to the lift, and that the volume of compressed air is equal to volume of water delivered. Based upon these assumptions the limiting efficiency beyond which the pump cannot go, as stated by Mr. Johnson, decreases with the lift as follows:

Lift Feet.	*Limiting Pump Efficiency.*
5	87%
10	78%
25	64%
50	52%
100	43%
130	39%

Upon the other hand companies selling this machinery claim to obtain good efficiency at lifts of 250 to 300 ft., and that they get their best results at lifts between 150 and 200 ft.

So far as the writer is aware, no tests more careful and comprehensive have been published than the tests made in San Francisco by Messrs. Browne and Behr, and reported in a paper before the Technical Society of the Pacific coast in 1890. These tests were abstracted in the *Engineering News* of June 8th, 1893. The best results obtained by these gentlemen are as shown in Table No. III.

Table No. III Showing Best Results Obtained by Messrs. Brown and Behr, Upon Experimental Air Lift Plant.

(1) No.	(2) Lift	(3) Submergence	(4) Water Gals Min.	(5) Air Press Gauge lbs.	(6) Cu. ft. free air per min	(7) Least H. P to Raise Water	(8) Least H. P. to Compress Air Isothermally	(9) Pump Efficiency %
1	15.3	69%	115	16.2	22.0	445	1.04	43%
2	35.	60%	87	24.	23.6	.770	1.46	53%
3	54.5	38%	26	16.1	26.0	.356	1.24	29%
4	75.2	43%	79	31.1	61.0	1.50	4.37	3[illegible]%
5	75.3	42%	67	27.6	46.5	1.27	3.12	41%

These tests were all made with a special well having a 3 in. eduction pipe and 0.9 in. air pipe let down outside the eduction pipe and returned into the lower end of same, discharging through a 5/8 in nozzle.

In Table No. IV is shown three tests that were made some years ago upon water works plants, and which have been published in various journals.

TABLE NO. IV. MISCELLANEOUS TESTS—AIR LIFT PUMPING PLANTS.

Place.	De Kalb.	‡Rockford. 4 St. Peter's Wells.	†Waukesha.
Lift ft.	143	85	100
Water, gals. per min.	207	1392	820
Air pres., lbs.	53	76	......
Submergence	52%	....	......
Cu. ft. free air per min.	*312	....	......
H. P. of water	7.47	30	20.5
H. P. of reserve air	*30.4	79.5	......
H. P. of steam cylinder	42.74	125.4	112
Efficiency of pump	24.5%	38%	......
Efficiency of pump and compressor	17.48%	24%	18.3%
Source of information	Eng. News.	W. Soc. Jour. 1897.	W. Soc. Jour. 1897.

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* Based upon plunger displacement.

† Single stage 2 cylinder compressor driven by a twin Corliss engine with steam and air cylinders tandem.

‡ Duplex air compressor.

In making investigations for additional water supplies the writer has had occasion to operate several air lift plants, the results from two of which are shown in Table No. V. In these tests observation of economy was of secondary consideration, and no measurements of the air supplied were made further than to record compressor revolutions and receiver pressure. The statement of air consumd is based upon 90% of the compressor displacement. It is believed, however, that the data represents approximately the results at these places under "every day" operation. The conditions in Plant No. 1 appear to be favorable for good efficiency; but in Plant No. 2 the conditions had changed since the installation, and at the time of the test were in many respects unfavorable to good economy with the machinery installed.

Table No. V.—Tests of Air Lift Pumps.

(1) Plant	(2) Lift.	(3) Submergence	(4) Water gals. min.	(5) Air Press Gauge lbs.	(6) Cu. ft free Air per min.	(7) Theo. H. P. to L. ft Water	(8) Theo. H P to Compress Air Iso.	(9) Pump Efficiency 7
Plant No. 1								
1 well	61 ft.	66%	330	65	167	5.08	18.0	28%
2 wells	63 ft.	65%	450	67	213	7.08	23.5	30%
Plant No. 2								
10 wells	160 ft.	24% to 44%	1000	65	2270	40.5	245.0	17%

It seems to be the general impression, and this is borne out by such tests as have been made public, that the efficiency of the air lift as a pump, not considering the compressor, ranges between 25% and 40% under favorable conditions and for medium lifts.

The compressor is, of course, a necessary part of this device. For the large majority of water works applications, single stage compression has seemed advisable and has been used.

Regarding the efficiency of steam driven machines, namely, ratio of the least power to compress the air isothermally, to the indicated power of the steam cylinder, Mr. Frank Roberts, in his very good book upon Compressed Air, places it at 60% to 75%, in well designed machines, and distributes the losses as follows:

	Percentage of Loss.
Machine friction	7½% to 10%
Initial heating	2% to 10%
Heating during compression	15% to 17%
Clearance, etc.	5% to 10%
Net efficiency total	74% to 60%

Mr. E. E. Johnson, in his paper before referred to, considers 46% and 57% fair results under gauge pressures of 43 lbs. and 135 lbs. respectively. The same paper cites an efficiency of 63% for a 14 in. by 22 in. duplex air compressor at Rockford. It is probable that no injustice will be done by assigning the values 60% to 75% for such machines as can properly be placed in the ordinary water works installation.

SHAFT AND TUNNEL METHOD.

The larger cities in the development of the ground water supplies have felt the need of some method of procuring the water, of greater efficiency than is possible by the use of the deep well reciprocating pump or the air lift; even in places where the static ground water level lies close to, or even above the surface, this need has been felt. As pointed out in the discussion above upon the hydraulics of wells, the flow is usually in direct proportion to the depression of the static ground water plane by pumping; and it will usually prove economical to depress this ground water plane to a considerable degree, where a large quantity of water is desirable, rather than spread the pumping machinery out over a large number of wells, which would be necessary in case the ground water plane is only slightly depressed. This condition has been met in a number of cases after the general manner indicated by Fig. 6.

In this method of development a shaft, of suitable diameter to accommodate the machinery, is sunk to such depth as seems advisable under the circumstances; and from the foot of this shaft one or more tunnels are driven laterally in such direction as to intercept the wells which it is desired to pump. The tunnel is usually well below the ground water plane, the depth of the shaft and the

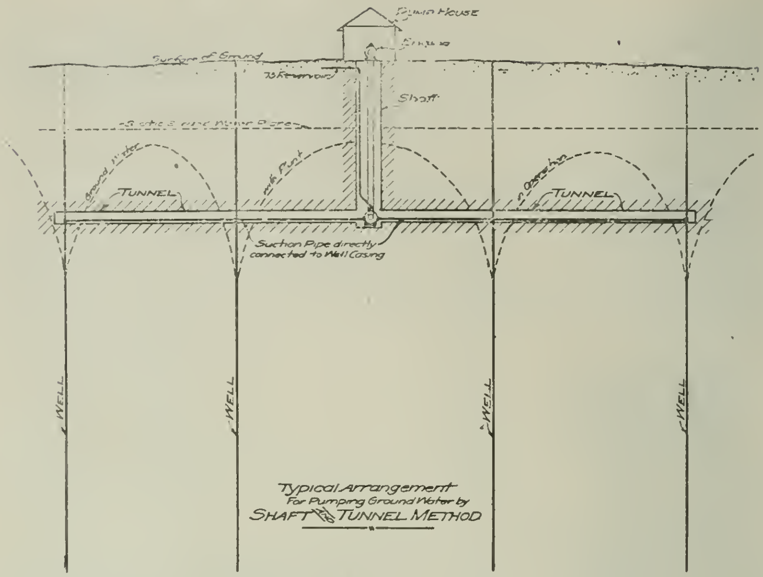
Pump House
Engine
Surface of Ground
To Reservoir
Shaft
Static Ground Water Plane
Ground Water
TUNNEL
TUNNEL
Suction Pipe directly connected to Well Casing
WELL
WELL
WELL
WELL
Typical Arrangement For Pumping Ground Water by SHAFT & TUNNEL METHOD

FIG. 6.—Shaft and Tunnel Method of Obtaining Ground Waters.

length of the tunnel depending upon conditions, both present and future. The wells are, of course, drilled from the surface of the ground, and their casings afterward cut at the tunnel level, where the proper fittings are inserted. The well casings may be tightly connected to a common suction pipe leading to the pump, as is shown in the illustration, or they may discharge directly into the tunnel, which, in such case, is used as a storage reservoir, and is inaccessible unless the water is pumped down. A direct connection between wells and suction pipes permits access at all times to the tunnel, and further permits the pump to draw the wells to suction depth below the tunnel grade, thus adding to their capacity. In developing a water supply by this method almost any class of pumping machinery may be used that conditions will warrant, and the coal economy is limited only by the highest class of pumping machinery manufactured. As the steam end of the pumping device requires the most attention, it is customary and advisable to place it at the surface of the ground. If the shaft is not too deep, vertical high duty pumping machinery may be used; the steam economy varying, as desired, between 80 and 140 million foot pounds steam duty. Where the shaft is deep, or where it is desired to use electric power, the matter comes into the field of the centrifugal pump. If the power is electricity a vertical shaft, pump and motor lends itself well to the arrangement; the motor, of course, placed at the top of the shaft on account of both care and dampness.

A vertical shaft centrifugal may also be used with an engine drive, the power being applied through a twisted belt (an awkward looking device), which, however, gives fairly good efficiency, or by the use of beveled gears, which become practicable if the speed is not too high. The use of gears, at the best, is less efficient than a belt connection and they are subject to easy derangement. Horizontal throw engines are also probably applicable to this case, although no engines have been manufactured except on very low lifts, where a cross compound Corliss engine has been used. The vertical rope drive permits the use of both horizontal shaft pump and engine, at high speed, and gives a very creditable efficiency.

Although minor applications of this general method of water development have been made for years, the first important application, as herein outlined, is believed to have been made at Memphis, Tenn. A general description of the conditions, and the method of developing the supply is given by the designer, Mr. T. T. Johnston, in a discussion before this Society in 1897. The shaft, at that place, is 80 to 90 feet in depth, and from its foot tunnels lead to the wells. The water is discharged directly into the tunnels, which form passages for the water to the shaft and reservoirs for its storage. The pumps installed are high duty Worthington verticals, and are said to have shown a duty of about 115 million foot pounds.

Two notable installations of the shaft and tunnel method have been made by Mr. Daniel W. Mead, of this Society—one at Rockford, completed about ten years ago, and one at Ft. Worth, Texas, of later date. The plant at Rockford has been described in several technical journals. The shaft was sunk to a depth of about 95 ft. through sixty feet of water-bearing sand and gravel. The foot of the shaft rests in clay, not sufficiently compact, however, to avoid the pneumatic process which was used in construction. The tunnels lie about 95 feet below the ground water surface, and accommodate suction pipes directly connected to the wells and pumps. Three pumping units were installed, each consisting of a single stage centrifugal pump, vertical rope driven by a compound condensing high speed engine located at the top of the shaft, in the pump house. Mr. Mead states that upon test the following efficiencies were secured:

Engine friction	90.0%
Efficiency of rope transmission	95.0%
Pump efficiency	87.0%
Total efficiency	74.8%
Steam duty	57.8 million foot pounds

The pump operates upon about 100 ft. lift; the maximum delivery of each unit is about seven million gallons per day. The pump efficiency, as stated, is remarkable, but this is somewhat offset by a somewhat larger engine steam consumption than would seem necessary. The engine consumption was intended to be 18 lbs. of water per I. H. P. hour, but the minimum of 24 lbs. was secured upon test.

The plant at Ft. Worth, Texas, is in many respects similar to the Rockford installation. The shaft is about 170 feet in depth, from the foot of which tunnels aggregating 2,000 ft. length lead to the wells. The pumping plant is in two units of five million gallons each, and each unit consisting of a three stage vertical shaft centrifugal pump, driven by a steam engine at the surface. The connection between pump pulley and engine is a quarter turn rope drive.

A plant very similar to the Rockford installation was installed at Elgin, Ill., some three years ago. At this place the shaft is 115 feet in depth, from the foot of which tunnels connect to four wells. Before construction of the plant the static water level of the wells was located at about 18 ft. below the surface of the ground. When the plant is operating at from two and one-fourth to two and one-half million gallons per day, the pump operates with about three feet head on the suction, indicating that the static level is pulled down about 100 ft. when pumping at the rates named.

VERTICAL SHAFT HIGH SPEED CENTRIFUGAL PUMP.

Just at present a new pump is entering the deep well field, and while it seems too much to expect that it will rival the high duty reciprocating machines, applicable to the lower lifts of the shaft and tunnel method, it has already assumed an important place in the pumping field. The writer refers to high speed vertical shaft centrifugal pumps of such diameter that they can be set in bored or drilled holes. It is believed that the earliest application of this device was made in the improvements to the water works of Moscow, Russia, completed in 1900. The plant was described by Mr. N. T. Simin, Chief Engineer, in the proceedings of the American Water Works Association in 1901. The pump was designed and built by the Forcot firm of Paris. Each pump, as installed, is accommodated in a 16 in. well, and at 1,440 rev. per min. lifts 812,500 U. S. gallons per day. The lift under which they operate is not specified, but, judging from statements in the paper, is about 50 ft.

In 1902, Mr. John W. Alvord, of this Society, in a report to the Chicago Clearing and Transfer Company upon the development of a large ground water supply at their proposed plant at Clearing, near Chicago, called attention to the possibilities, by this means of pumping. At that time no device of this kind had been built in America. At the request of the Company, Mr. Alvord prepared a design of an experimental pump, which was constructed by the Company under Mr. Alvord's direction. The pump was so designed that various forms of impeller could be tried, and in the fall of 1902, the pump, equipped with the best impeller, showed an efficiency of 50% when operating at 1,640 rev. per min. and discharging 835 gals. per min. against a head of 38 ft. The experimental pump had one impeller only. The pump was so designed as to be accommodated in a 12 in. hole. The test at Clearing was under the direct charge of Mr. M. E. Shire, engineer for the Company. Owing to

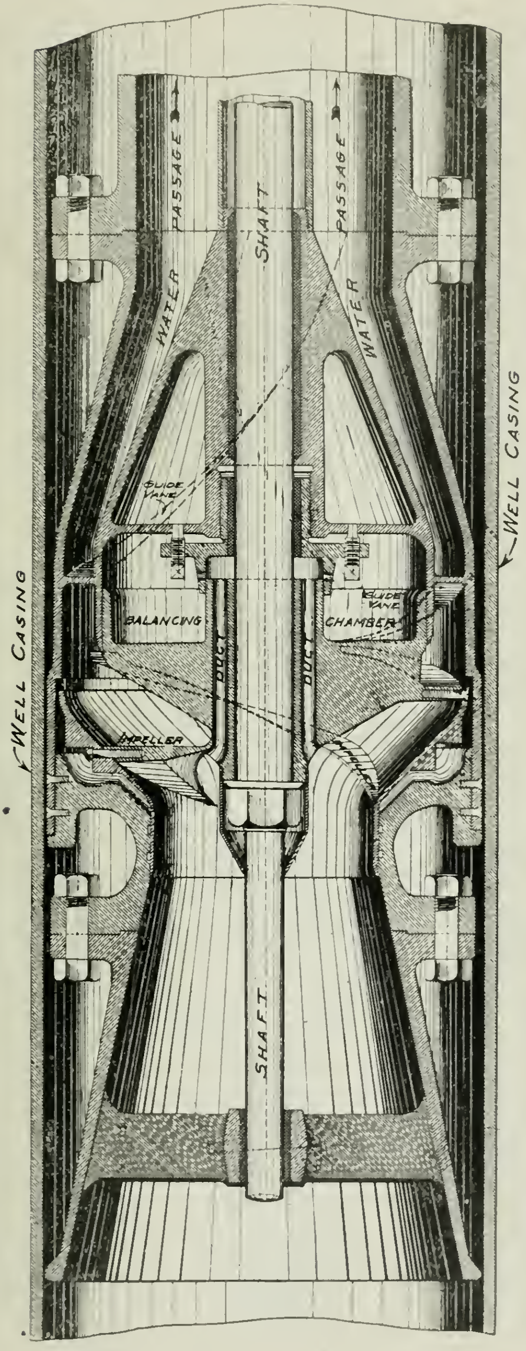

FIG. 7.—Alvord's Deep Well Pump.

reasons entirely apart from the water supply, the construction at Clearing was delayed and has not yet been carried out. The experimental pump has been recently turned over to Prof. Mead, of the University of Wisconsin, who has made a series of tests with various forms of impeller, which, it is understood, will form the subject of a bulletin to be issued shortly by the University.

The successful operation of a device of this kind, at high speed, cannot be accomplished without proper provision for handling the down thrust; and, inasmuch as the balancing device of Mr. Alvord's pump was one of the most satisfactory features of its operation, it is worth while to note it especially. Its principle, like most means of balancing, depends upon the head of the discharge water entering around the edge of the impeller, and applying its pressure to the under side of the same. The balancing chamber immediately above the impeller has the office of relieving the pressure from above so that the head below the impeller can act.

It will be observed in Fig. 7 that a duct in the shaft connects the balancing chamber with the suction side, and that the entrance to this duct is controlled by a port that is opened and closed by a slight fall or rise of the impeller and shaft. By this arrangement as the pump comes up to speed pressure is produced in the discharge passage and, by leakage, under the impeller. By the proper apportionment of areas, this pressure tends to raise the impeller and close the port, in the balancing device. The leakage into the balancing chamber from the discharge passage causes the pressure to rise in the balancing chamber in sufficient amount to overcome the up-thrust. In the test at Clearing it was found that as the pump came up to speed the shaft was lifted about one-sixteenth of an inch, and rode clear of the balls in the ball thrust bearing provided at the top of the shaft. Fig. 8 is taken from the patent drawing and shows this device as it might be applied to very high lifts, the number of balancing chambers being multiplied. The pump, as designed by Mr. Alvord, is, of course, capable of compounding, as is now done in centrifugal pump practice for high lifts. By increasing the number of impellers, high lifts can be accomplished at medium speeds.

At about the time that Mr. Alvord was making his plans the subject seems to have been taken up by Mr. Byron Jackson, of San Francisco, a manufacturer, who has done some creditable work in centrifugal pumping. His company is believed to have been the first to place this type of machine upon the market. The pump, now in operation in several water works plants, is in many respects similar to that of Mr. Alvord. The first installation was made under the advice of Prof. Mead at the Pabst Brewery at Milwaukee. This pump is a five stage machine, and is accommodated in a 15 in. hole. It is designed to lift 700 gals. per min. against a net head of 220 ft. The speed of the shaft is 1,300 rev. per min. and the pump is engine driven, a twisted belt transmitting the power. The lift at present is 150 ft. Steam cards taken by the station engineer are

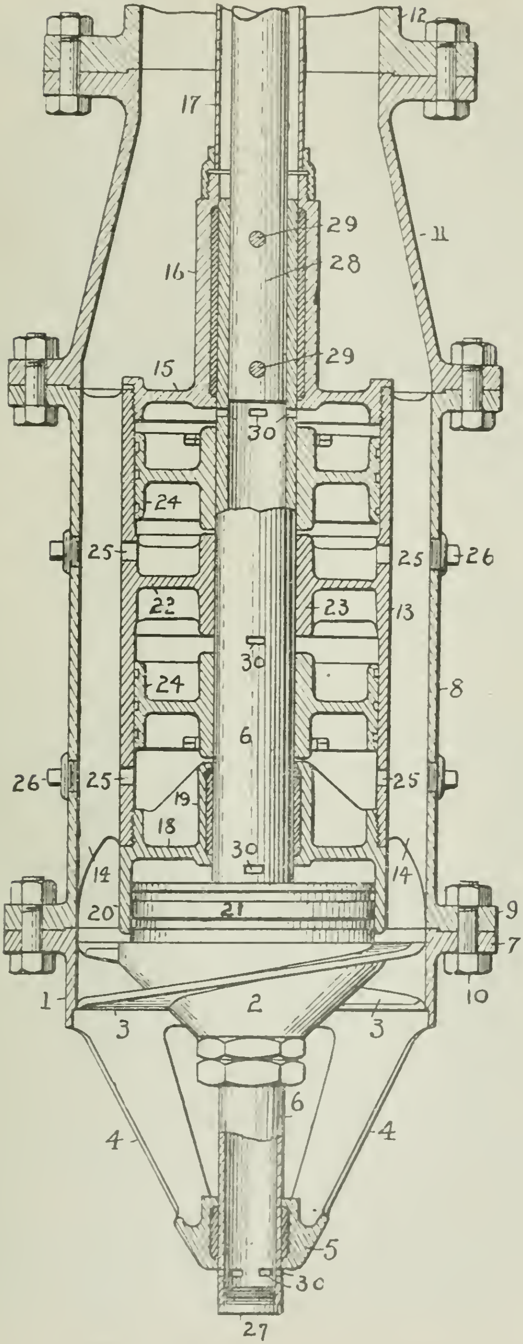

FIG. 8.—Application of Balancing Device of Alvord's Rotary Pump for Extreme Lifts

said to indicate an efficiency from engine cylinder to water delivered of 56%. It is probable that this means not less than 65% pump efficiency. A similar installation has been operating at Waterloo, Iowa, since 1905.

An interesting electrically driven water works plant has just been completed at La Grange, Ill., which includes centrifugal pumping machinery for the development of a deep ground water supply, and a subsequent pumping by a second set of pumps into the distribution system of the city. The new electric plant replaces a steam driven water works in which the air lift was used for pumping the well supply. The electric current is furnished by a large generating station at Maywood, some four or five miles distant, from which a number of suburban water and light plants are to be supplied. Two wells formerly drilled furnish the supply. They are located about 100 ft. apart. Their dimensions previous to the improvements were as follows:

Well No. 1 (north well).
6 in. hole to depth of 40 ft. below ground.
5½ “ “ “ “ “ 810 “ “ “
5 “ “ “ “ “ 1310 “ “ “
4 “ “ “ “ “ 2024 “ “ “
Well No. 2 (south well).
8 in. hole to depth of 130 ft. below ground.
6⅞ “ “ “ “ “ 1364 “ “ “
6 “ “ “ “ “ 2045 “ “ “

The wells derive the major portion of their supply from the Potsdam sandstone formation. Tests preliminary to the installation showed the static ground water level to be 26 ft. below the ground surface. The wells are about equally efficient in regard to water delivery, and furnish when operated separately 360 gals. per min. under a 40 ft. drop, corresponding to a water level of 66 ft. below the ground surface. Operating together the combined delivery was 490 gals. per min. at the same depression in water level as before. Before installing the pumps the wells were reamed out for a depth of 120 ft. to a diameter of 16 in.. and a 15 in. internal diameter casing placed in each down to rock about 30 ft. below the ground surface. Fig. 9 shows the principal dimensions, speed and capacity of the two units installed. The units are duplicates. The pump is driven by a 25 H. P. Westinghouse three phase, 440 volt induction motor running at 1120 rev. per min. It is connected to the shaft by a flexible leather link coupling. The weight of the armature is carried by a separate thrust bearing in the motor casing. A portion of the down thrust is taken by balancing chambers of the Jackson type just above the pump runners.

It is evidently considered that this balancing arrangement does not have sufficient elasticity, for an additional water step bearing is provided, on the pump head at the ground level. Until the pump comes up to speed the shaft is carried on a roller thrust bearing

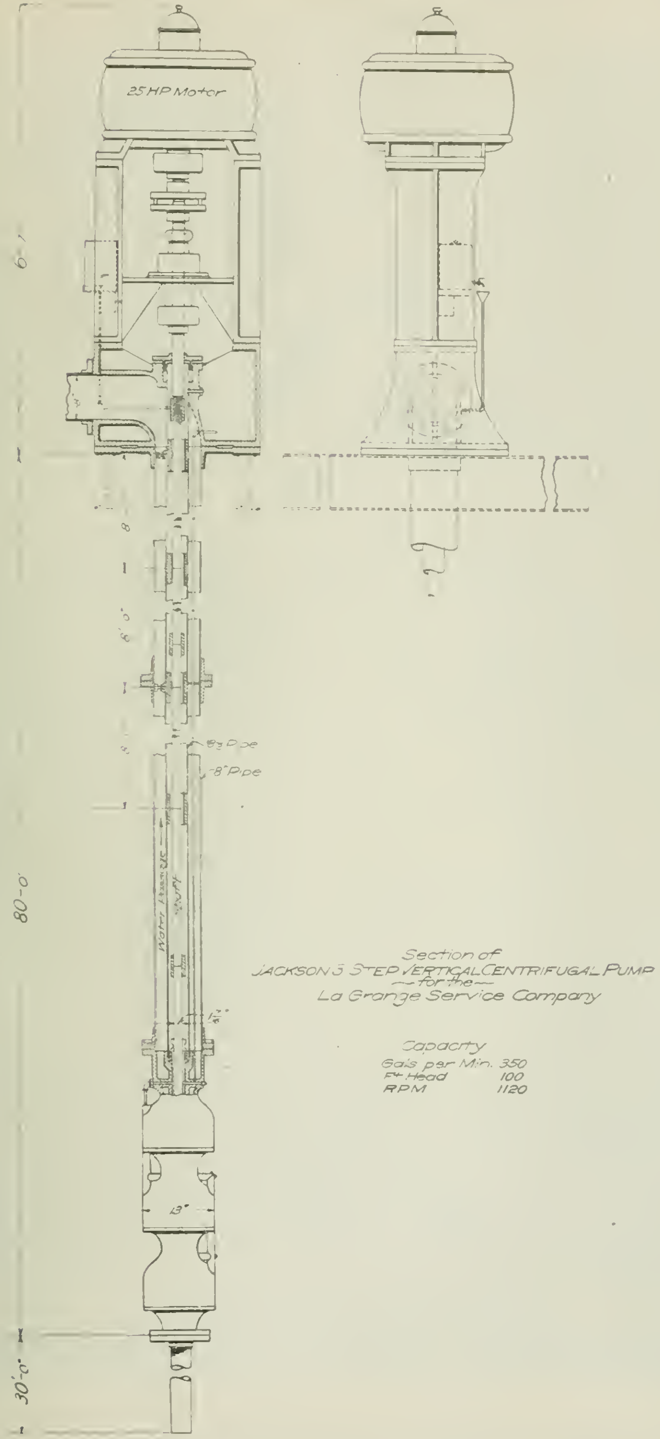

FIG. 9,— Electrically Driven Vertical Centrifugal Pump, LaGrange, Ill.

on the pump head. In the drawing the well casing is not shown; the pump hanging free and entirely independent of it. The water is discharged through the annular space between the 8 in. uptake pipe and the 3½ in. pipe which encloses the driving shaft. The shaft is supported by babbetted bearings at intervals of 8 ft. Each alternating bearing forms a coupling for the 3½ in. pipe. Each of these alternate bearings are centered and held firm by means of three jam-nuts equally spaced around the combined bearing and coupling. Provision is made for giving the bearings and impellers a small amount of oil, but since the first few weeks of operation no oil has been supplied except to the impellers, the water lubrication apparently being sufficient. Each pump is now working, when operated alone, under about 75 ft. head, friction not included, and delivers 405 gals. per min. It was hoped to present a duty test of this machine in this paper, and it is expected that data can be secured in time to include it when published in our JOURNAL. The preliminary run seems to indicate that the pump efficiency is close to 50% and the motor efficiency 85%. The unit in well No. 1 has now been in constant operation for about eight months. The unit in well No. 2 has just been installed. The pump operates very nicely. When in the room with the pump, one has almost to stand directly in front of it to perceive that it is running. The entire pumping plant was designed and built by the Byron Jackson Machine Works of Oakland, Cal. The plant was designed and supervised by Messrs. Sargent & Lundy, mechanical and electrical engineers of this city, under the advice of the writer and his associate.

This subject would not be complete without reference to the propeller pump designed and built by Mr. P. K. Wood, of Los Angeles. It is believed that the use of this pump antedates the Moscow installation. Fig. 10 shows an illustration of this pump. The cut will sufficiently explain its method of operation. In the illustration the propellers are shown equally spaced, the lowest impeller, of course, being below the static water level of the well. Mr. Wood discovered that these propellers may be compounded, and when bunched at the bottom of the shaft the result is the same as by the arrangement shown.

Two installations have been made in this vicinity, the first at Batavia, Ill., where a pump is driven by a Pelton water wheel, and the second at Madison, Wis., where the pump is electrically driven. Prof. Turneure tested one of these pumps at Madison previous to the permanent installation in the city water works, and reports the overall efficiency of the driving electric motor, belt and pump at 40 per cent. Prof. Turneure estimates that, allowing for motor and belt, the pump efficiency is about 50 per cent. With some improvements in its mechanical details this pump should give a good account of itself.

DISCUSSION OF PUMPING METHODS.

Without attempting to describe all of the special devices for handling ground water, the writer has above covered the general

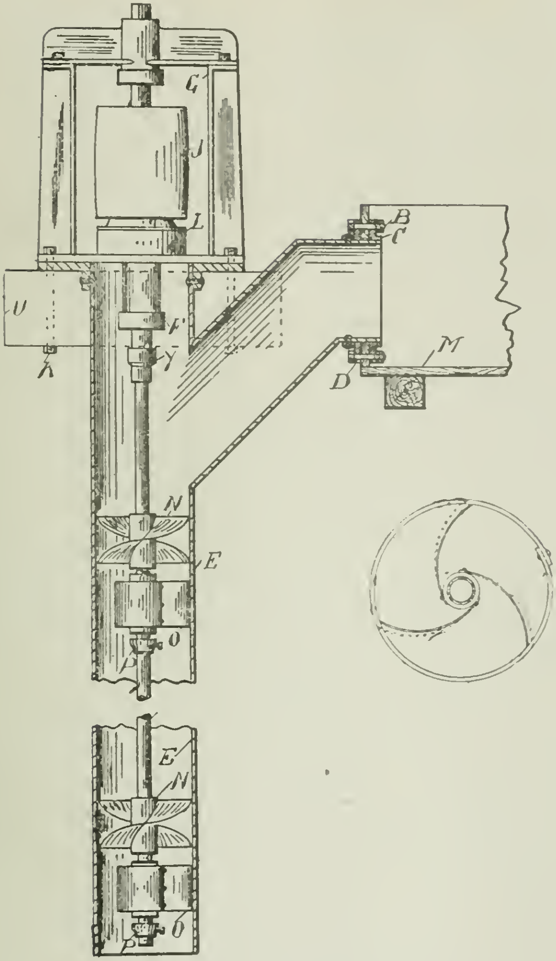

FIG. 10.—The Wood Propeller Pump.

methods that have been successfully employed. All of these methods are in use and will probably continue to be used. Each has its place. For low lifts and small quantities, the deep well reciprocating pump has the field, and will probably continue to be used for estates, institutions and villages.

The air lift has a field entirely apart from the pumping of water supplies. Its lack of moving parts in contact with the fluid handled lends it especially to the pumping of chemicals of corrosive nature. It is capable of multi-stage application where space is available, and thus a deep submersion can be avoided. This fits it for mine draining and like operations. It is likely to continue to find use in water works installations where the highest economy is not warranted. A number of plants have recently been installed to supply emergency water for fire service. For such use as this the air lift is without a peer. Given sufficient power behind, it there is no device capable of drawing a larger supply from a hole of a given size, even at considerable lifts. In many cases where this pumping device has been discarded as extravagant of fuel, its lack of economy can be traced to unintelligent operation. It has suffered with other pumping devices by the receding static ground water levels in this section of the country. While it is a simple matter to alter the air lift pump proper for increasing lifts, the machinery of the air compression cannot easily be so altered, the greater lift necessitating greater pressures and volumes for economical results.

The shaft and tunnel method is applicable only to special cases. Where conditions will warrant its use it is capable of the highest coal economy of any device used in deep well pumping. In most cases this saving in fuel must be more or less offset by a heavy interest charge, as shaft and tunnel construction below the ground water plane is more or less uncertain and expensive. Experience has proven the folly of investments of this kind without most careful study of the local underground hydraulics, both past, present and future. The investment once made cannot be easily altered in accordance with modifications that afterward seem desirable.

Vertical shaft high speed rotative pumping machinery of the so-called centrifugal type is undoubtedly destined to occupy an important place in the deep well pumping field; in fact, it may be said that it has already occupied this position. It is especially applicable to large supplies from deep sources. The considerable rotative speed of these machines lends it specially to plants where electricity is the source of power. Until some one places a vertical shaft steam turbine upon the market, in units of medium size, its connection to the steam engine will be somewhat awkward, although not seriously lacking in efficiency. While somewhat less in fuel economy than the shaft and tunnel method, it has the advantage of a smaller interest charge. It has a further advantage in that it is probably more adaptable to changing underground conditions than any other deep well pumping device capable of the same duty. It is practicable to so design these pumps that they be depressed upon occasion and adapted to higher lifts without increased speed by the addition of impellers.

DISCUSSION.

Mr. E. N. Layfield, M.W.S.E: Mr. Burdick has been so clear in his paper that I do not know that there is very much I can say about it, but for the benefit of those who, like myself, know little about the subject, I want to ask Mr. Burdick to explain a little more fully the significance of those lines in connection with Fig. 2. I think I understand fully now what he means, but when he first started to read the paper I did not know what he meant by the flow lines. Take, for instance, the bottom line of Fig. 2. I suppose that Mr. Burdick means that as the 130 feet line intersects the line for 150 gallons per minute, then that is the flow of the well if you pump from that depth.

Mr. Burdick: Yes that is correct.

Mr. Layfield: It is interesting to note those lines all run so straight in so many of those wells, and that there is a very decided curve in some of the others; for instance in Fig. 1.

Mr. Burdick: I will say with reference to that curve line, that it is a theoretical curve. That would be the curve of a well supplied by a pipe, and the practical curve would lie somewhere between that line and a straight one.

Mr. Layfield: Is that curve due to the ease with which water flows through earth?

Mr. Burdick: That curve would probably represent the flow of a well in which the water reached it through a passage. The line of flow through a passage is different from one resulting from a flow through a porous material. The line of flow in sandstone is the same as that through sand, the water evidently not coming through passages in the stone, but through the body of the stone itself, which is quite porous.

Mr. Layfield: Take for example this same line spoken of before. If the static level were at about 60 or 70 as in Fig. 2, if you wanted to get the flow of 150 gallons a minute you would place your tunnel at a depth of 130 feet, or if it was merely one of those other types of pumps you would place your pump at that depth.

Mr. Burdick: Yes, you would draw the water down to that depth to get that quantity. The place at which the pump would be set however would depend upon the kind of pump used.

Mr. J. L. Hecht, M.W.S.E: It may be of interest to know, in connection with the wells referred to in Fig. 1, that some extensive tests have recently been made on these wells and it has been found that the heavy dash line curve given as a probable curve by Mr. Burdick, is almost exactly what we find the wells to do by getting about six points and plotting them. The curve we actually get is a trifle more curved than the one given in Fig. 1.

There is another interesting point in connection with these wells, shown in Table No. I (the Oak Park Wells are the ones I am referring to). It was found that during the period from 1890 to 1905 the water had dropped from 100 to 140 feet. We find now that in the last two years the water has apparently come up between 8 and 10 feet. This may be due to the fact that some of the load has been taken off of these wells, the Austin district having been put on to the Chicago pumping district.

In Mr. Burdick's paper concerning the Airlift, regarding the question of whether in raising the water the air forms a piston or whether it mixes with the water, our tests seemed to indicate that we got a better efficiency when the water flowed from the well in a steady stream mixed with the air. The only time that the water comes out with a spurt of water, then air and then water again, is when the well is not getting sufficient air and at these times the well is not as efficient as when getting a sufficient quantity of air and flowing in a steady stream.

There is another point of interest in Table No. V. In these same wells, mentioned at the bottom of the page as plant No. 2, the efficiency was 17%, taking one particular well in which the air pipe extended 172 ft. from the surface. The pipe was lengthened 20 ft. and was increased from 1¼ in. to 1½ in. in diameter so as to cut down the friction and the efficiency was brought up to 22%. This well with 172 ft. of 1¼ in. pipe was giving 180 gallons per minute; when the pipe was increased to 1½ in. and extended 20 ft. further, we got 245 gallons per minute; an increase of approximately 33% in the quantity of water and an increase of about 25% in efficiency.

Mr. O. C. Spurling, M.W.S.E.: It may be interesting to give some results obtained at the Hawthorne Plant of the Western Electric Company. There is there a double acting deep well pump with a single hollow rod, the water being discharged on the down stroke through the hollow rod into the main pipe.

The average results obtained from a continuous run of 168 hours showed that 226 gal. per min. were pumped against a head of 80 ft. with a consumption of 12.5 pounds of steam per minute. The consumption of steam per hydraulic horse power hour is 164.3 pounds and as the steam delivered to the pump costs 35 cents per thousand pounds, the cost per hydraulic horse power hour is 5.75 cents, and for pumping 1,000 gallons, 1.93 cents.

I have endeavored to compare these results with the Byron Jackson pump at LaGrange and by assuming the efficiency of the pump equal to 50% and of the motor equal to 85%, I find that 1.75 kilowatt hours are required by the motor per hydraulic horse power hour.

If this pump were in use at our Hawthorne Plant, the cost of current delivered to it would be 2 cents per kilowatt hour so that with this combination the cost per hydraulic horse power hour would be 3.5 cents and the cost of pumping 1,000 gallons would be 1.18 cents.

Considering the wells referred to in Table No. V, using compressed air where 450 gallons per minute were pumped against 63 feet head with 67 pounds air pressure and with a consumption of 213 cubic feet of free air per minute, I find that if we assume the cost of 1,000 cubic feet of free air compressed to 75 pounds to be 7 cents (the Western Electric Company's cost for air compressed to 75 pounds is 8 cents per thousand cubic feet of free air) the cost per hydraulic horse power hour is found to be 12.5 cents and the cost of pumping 1,000 gallons, 3.3 cents.

If the results of tests made at LaGrange are available, I should like to know the actual horse power taken by the pumps when running under normal conditions, also the actual efficiencies of pumps and motors.

Mr. M. K. Trumbull, M.W.S.E.: I would ask Mr. Spurling if his figures include the depreciation of machinery, interest charges, etc.

Mr. Spurling: The figures given are for steam, electric and compressed air power, respectively, delivered to well site and include a 15% depreciation on a diminishing value averaging 11.12% on the original investment of the steam, electric and compressed air power plants, respectively, when considered for a period of 5 years.

As the Hawthorne Plant is only about 2 years old, the depreciation charges are very high and the figures given for cost of steam and electrical energy will undoubtedly be reduced this year. No interest charge is included, nor fixed charges or operating expenses for the pumping plants are included in my figures.

Mr. Trumbull: It occurred to me, in looking at the figures, that the mechanism and details of the centrifugal pump are rather delicate, and I would ask if matter carried in suspension in the water would have a tendency to clog the working parts of the pumps to any great extent?

Mr. H. Gansslen, M.W.S.E.: I have been much interested in this paper and would like to give a few figures which I compiled recently. It was required in the vicinity of Chicago to pump water out of a deep well of about 1,800 feet depth to the amount of 250 gallons per minute and the water level drew down about 110 feet below ground level when pumping that amount. The owner of the well used to pump the water with an ordinary deep well pump with a steam head, but then called for the air lift, hoping to reduce the enormous steam consumption by doing so. I took occasion to look into the steam consumption of various types of pumps, and it turned out that the air lift proposed by several concerns here took just about as much steam to pump that quantity of water as his old style steam head—that is, about 1,200 lbs. of steam per hour. As there was only clear water to be pumped, there was certainly no reason for installing an air lift. In looking around further I came across a somewhat novel deep well pump. I think it is called the Luitweiler pump—which is claimed to be a reliable pump. Not having been able to obtain any information as to its efficiency, I thought perhaps one of the gentlemen present might have some data on that subject, and I would be pleased to hear something about it. It figures out that it will take only one-third of the steam of either the air lift or deep well pump with steam head, if driven, for instance, by a modern automatic steam engine. The water column with this style pump does not seem to come to a rest, which may account for the high efficiency to some extent.

President Abbott: The column of water would naturally come to rest when the moving pistons come to rest.

Mr. Gansslen: As there are two pistons in the pumping cylinder, which are driven by cams that are mounted on the driving shaft but not exactly diametrically opposite, the column of water is in motion continuously.

Mr. Hecht: The Luitweiler Pump is operated with cams instead of having cranks. It has a double plunger arrangement, the one being inside of the other; the cams being set so that one plunger picks up the water just before the other one comes to rest. In reply to Mr. Abbott's question; the cams are not set 180 degrees apart. Just how efficient this pump is I do not know.

Professor D. W. Mead, M.W.S.E.: I am greatly interested in this subject, but have not had an opportunity to read the paper carefully.

In regard to the Luitweiler pump I would say that it is one of the class of pumps that are termed continuous flow pumps, run on essentially the same idea as the Whitworth quick return mechanism used on shapers in the machine shop. The plungers come up slowly and go down rapidly; the second plunger starts up before the first one stops, and hence there is one always ascending and the column of water does not come to rest and shocks are avoided.

This subject of deep well pumping is growing in importance. It is not only of importance in the matter of water supply, but it is of considerable importance in the mining region. In southwestern Wisconsin in the lead and zinc district there are many small mines where the question of drainage is important. The quantity of water to be moved is not large, as we would ordinarily speak of large quantities of water, but it is of sufficient amount to make the question of pumping an important one to these small mining interests. In these localities the question of removing the water cheaply from the mines and in small quantities is becoming important. Where mines are large and important and the quantity of water to be removed is comparatively large, the question of pumping is not as difficult because it admits of the application of a higher grade of engineering skill, of more generous treatment, and much larger expense in its treatment, and hence can be solved more satisfactorily.

In the smaller mines the resources will not admit of the employment of engineering advice, nor the installation of expensive machinery. The plants installed must be those that can be selected and installed by the mine owners with such skilled help as may be easily available.

The deep well centrifugal pump described in the paper seems to be one of the most satisfactory solutions for deep well work, where the quantity of water to be pumped, amounts to 250 to 1,000 gallons per minute. Where smaller quantities are to be pumped other types of machinery can perhaps be used to greater advantage. I have installed a number of these deep well centrifugal pumps operated by steam engines, all of which are working satisfactorily.

In regard to the question raised as to the wear of this class of machinery, I would say that I do not think the pump at Waterloo, Iowa, has been taken out of the well since it was first put in, and it has been running about two years. In the deep well pumping plant installed at Rockford, Ill., in 1898, where a larger form of centrifugal pump was used in an open shaft, the pumps have now been running essentially eight hours per day for about nine years, and they are practically in as good condition to-day as at the time they were installed. They were inspected a short time ago and showed little wear and apparently no decrease in efficiency. I think that is one point very strongly in favor of that class of machinery. The sand passes through without lodging in the bearings and without any serious effects.

There is one point I think should be emphasized in regard to the selection and installation of various types of machines. The object should always be the selection of a plant adapted to the peculiar local conditions. The deep well plant at Rockford is installed on the shaft system; the quantity pumped is large. Where such large quantities are needed there may be reason for a shaft system on account of the disadvantage of multiplying the units, but where the quantity needed is small, the expense of the open shaft system is too great. My attention was called sometime ago to a report recommending a shaft system similar to the Rockford system. I had occasion to review the report and found that the cost of such an installation would be about $150,000 in order to assure about three million gallons of water per day; by applying the deep well centrifugal pump with small wells, the cost would be reduced to about $50,000, or about one-third of the original estimate.

Through the kindness of Mr. J. W. Alvord, and with the consent of Mr. Porter, of the Chicago Clearing and Transfer Company, the owners of the pump, the first Alvord pump has been presented to the University of Wisconsin, and has been subject to numerous tests and experiments. A bulletin is now in press and will soon be published, giving quite a complete set of tests, not only on the Alvord type with its impeller, but on some impellers designed for experimental purposes. When published, copies of this bulletin can be obtained by applying to the Librarian at the University of Wisconsin.

In explanation of the nature of the tests made I would say that no attempt has been made to obtain high efficiency from the impellers used, but simply to investigate the general principles of operation. The tests with the Alvord impeller do not show results as good as undoubtedly can be secured, although efficiences were sufficiently high to show that the pump has a broad field for general usefulness.

The first Jackson pump, illustrated in Fig. 9, was installed for the Pabst Brewing Company of Milwaukee. In fact Mr. Jackson designed the pump for the Pabst Company and the pump was installed and gave good satisfaction; there was some trouble with the bearings at first, but this was remedied and since then the pump has worked satisfactorily. The Pabst Company have removed the inner pipe, thus permitting the shafts to run directly in the water, and they find the results are fully as satisfactory as with the interior three inch pipe, which was furnished to prevent the friction of the shaft rotating in the column of water. The shaft was 1.75 in. in diameter, the inner pipe 3 in. and the outer or discharge pipe 9 in: in diameter.

In regard to the Wood propeller pump; it should be noted that it is held in place by strong springs as shown in Fig. 10, the idea of this construction being, that the pump can be slid down in casing already in place and held by the contact of these springs. The idea of the design is that where these springs are compressed they will be compressed uniformly, and the expanding of the springs is supposed to center the pump and hold it in place in the pipe casing. Most of the troubles with this pump have been due to the fact that the springs do *not* center the shaft properly, but throw it out of linne, due to unevenness in the spring itself and also to the fact that the alignment of the well casing is not true. The result is that when rotating at high speed the shaft will often break on account of these conditions. I believe this pump has a useful field provided it is properly constructed. It can be well constructed providing the bearings are made without springs, put in a pipe that is carefully prepared to receive it, and hold the shaft in perfect alignment.

Mr. Perry L. Hedrick, M.W.S.E.: Some years ago I made a flow test of an artesian well by the air lift method. The well was 1,572 ft. deep and cased to rock with 6 in. well casing; the water level when the well was at rest was 100 ft. below the point of discharge when under test. In order that some reliance might be had upon the results, a very carefully constructed weir box, which was provided with a hook gauge, was used to measure the water flow and all pressure measurements were taken with test gauges.

I take exception to the illustration which shows the operation of the air lift as dependent upon the "piston like" layers of air and water. The experiment showed that the operation was only similar to that under three sets of conditions:—

First, When the submergence is insufficient.

Second, When the submergence is proper and the air supply too large.

Third, When the submergence is proper and the air supply is too small.

When a proper amount of air was supplied and at a proper pressure (the submergence being correct) and admitted under proper control, the flow of water from the well was practically a continuous stream.

It is customary to use an air pipe of uniform diameter throughout, upon which is placed an ordinary stop valve to control the air flow; such an arrangement did not admit of sufficiently delicate regulation to give the most economical result. A small metallic disc of No. 12 gauge inserted in the air pipe allowed of much better control of the air pressures and also made it possible to pump the same quantities of water at lower pressures. It may be of interest to know that with a hydrostatic head of 80.5 lbs. and an air pressure of 81.5 lbs. there was obtained a flow of 406.3 gal. per min.; the hydrostatic pressure was obtained by gauge pressure and by direct measurement.

The following is an example of flow while using a 0.875 in. disc.

The submergence before operation was 188.3 ft.—(81.7 lbs. gauge) and the lift 111.5 ft.; after the water level had fallen to its operating level there was a submergence of 182 ft.

The following gauge pressures upon the well would give for
79 lbs. a flow of 346 gals. per min.
80 lbs. a flow of 353 gals. per min.
81 lbs. a flow of 371 gals. per min.
82 lbs. a flow of 381 gals. per min.

The pressure could not be held at 78 lbs. as the well would only flow intermittently, *i. e.*, gush forth now and then.

For a 0.5 in. disc and 178 ft. submergence at beginning, the well flowed on 75.5 lbs. and gave 310 gals. per min. In endeavoring to reduce the air pressure to 74.5 lbs. the valves upon the air pipe would close entirely and would do so before the well stopped flowing. Hence it is conclusively shown that the air necessary to pump 310 gals. per min. is the quantity which flows at an excess of one pound pressure over and above the back pressure due to the hydrostatic head.

The volume per minute for the difference is, according to Hiscox's formula, for a 0.5 in. orifice in thin plate 96.4 ft. free air which is equivalent to 0.31 cu. ft. free air per gal.

For a 0.75 in. disc, same submergence.
75 lbs. gave a flow of 323 gals. per minute
76 lbs. gave a flow of 350 gals. per minute.

The gauge could not be held at 74 lbs., as the flow would be only in spurts and allow the pressure to vary from 74 to 76 lbs.

For a 0.5 in. disc, 160 ft. submergence
70 lbs. a flow of 321 gals.—pres. head equivalent to 161 lbs.
69 lbs. a flow of 310 gals.—pres. head equivalent to 158.7 lbs.
68 lbs. a flow of 293 gals.—pres. head equivalent to 156.4 lbs.

On 67 lbs. the well stops flowing.

For a 0.5625 in. disc, same submergence.
73 lbs. 331.5 same submergence.
72 lbs. 329.7 same submergence.
71 lbs. 323 same submergence.
70.5 lbs. 313 same submergence.
70 lbs. 287 same submergence.
69 lbs. 268 same submergence.

Valves closed at 68 lbs. pressure, as the disc was too large.

The compressed air for the test (which extended over a period of two weeks) was taken from that furnished by a cross-compound air compressor which under two eight hour tests developed 320 H. P. for the steam end and 289.7 H. P. for the air cylinders while running under full load and compressing to 100 lbs. gauge pressure. The volumetric efficiency found by actual measurements of the air compressed was 77.4%.

Cost of Engine H. P.=0.479 cents.
Cost of Boiler H. P.=0.834 cents.

President Abbott: It would appear to me that in the case of a reducing diaphragm with a small orifice the results obtained might be misleading if the air compressor was running at a constant speed, without the introduction of an obstruction in the pipe would serve to raise the pressure a few pounds, and not reduce the quantity of air pumped.

Mr. Hedrick: I was careful to take the measurements. The pressure of the air was just equal to the hydrostatic head of the water at all times, with a variation in excess of that of less than one-half pound.

President Abbott: In taking the pressure each side of the diaphragm, did you note the difference?

Mr. Hedrick: It was usually the same.

President Abbott: That showed that the volume of air passing was relatively small.

Mr. H. P. Boardman, M.W.S.E: Referring to Fig. 8, it looks to me as if that might be called a screw pump, or is that a centrifugal pump?

Professor Mead: That pump is undoubtedly a screw or propeller pump. Mr. Jackson made some experiments with a similar pump, in which he used very nearly the same form of propeller; they were made to compare the centrifugal with the screw pump. The best he was able to do was to secure 50% efficiency.

In the air lift pump the efficiency is necessarily low on account of the many transformations of energy and its poor method of application. The action of the air applied, is simply to reduce the specific gravity of the water, thus causing the column to rise and overflow. I have made a number of tests with the air lift and found efficiencies running as low as 8% and the best efficiency I have ever obtained in practice has been 26%. These were tests on air lifts installed at various water works plants. There is a great deal we should know about the air lift which we do not.

We are about to undertake at the University of Wisconsin, a series of tests with the air lift and expect to determine as far as practicable the underlying relations between quantities of air and water, lift, size of air and discharge pipe, etc. Much of this may be known, perhaps, to the air lift manufacturer, but the information is not well established among the engineers.

Mr. Hedrick: I will say that the tests which were made on the cross-compound air compressor showed the cost to be less than 1 cent per H. P. per hour. In regard to the slip of the air bubble, I believe there is a slip and that the air bubble travels through the water at a rate of about 5 feet per second.

Mr. J. W. Schaub, M.W.S.E.: I am rather surprised at the explanation given of the principle involved in the action of the air lift in changing the specific gravity of the water. I am interested in this only in connection with sand pumps, where hydraulic pressures of 150 to 200 lbs. per sq. in. are used, where the explanation here given cannot obtain, because the deeper we get down with our sand pumps the greater is the efficiency.

President Abbott: That is true with all air lift pumping.

Mr. Schaub: If that is true then the efficiency for air lifts must be very low, while that does not obtain at all with the sand pump.

Professor Mead: There are pumps where the velocity of a jet of water, air or steam is the motive force which raises the water; but in the ordinary air lift the air acts principally by reducing the specific gravity of the water.

Mr. Schaub: The velocity of the discharge may explain the action of the sand pump, as the method of discharge does not cut any figure either way.The ratio of depth to discharge should be about as the author says; to get the best efficiency the ratio should be about 50%, but, the efficiency increases with the depth so that for depths of 100 feet it seems to work better than for depths of 50 feet. I am surprised that the introduction of air changes the specific gravity of the water sufficient to raise the water in the air lift.

President Abbott: In the cut shown, Fig. 4, it would seem that the only effect it could have would be to reduce the weights of the column.

Mr. Schaub: The water in passing through the nozzle in the sand pump takes up the surrounding water and sand with it. I always thought that the air lift operated on the same principle, but in this I am evidently mistaken.

President Abbott: The air is discharged at practically no velocity. The air discharges opposite to the flow of water.

Mr. Boardman: Why would not the principle of displacement explain this air lift? Two bodies cannot occupy the same space at the same time. The bubbles displace their volume of water, and since there is no free outlet for them they swell the volume of the combined column of water and air until it overflows at the top.

CLOSURE.

Mr. Burdick: In reference to the principle of operation of the air lift as stated in the body of the paper, when Mr. Frizell asked for his patent on the ground that he lifted the water by means of injecting bubbles, thereby lightening the specific gravity of the column and causing flow, the Patent Office rejected the application on the ground that it was contrary to physical law. The Patent Office rightly claimed that by no process could the air reduce the specific gravity of the column. The claim of the formation of piston like layers mentioned in the patent of Dr. Pohle, apparently explains the phenomenon, and yet it is questionable whether any such action takes place. Reference has been made in the body of the paper to an explanation of the fundamental principle of the air lift, printed in the Engineering News of June 8, 1893. The writer believes this to be the correct explanation and inasmuch as the paper has brought out considerable discussion upon this point, it will, perhaps, be of interest to add to the discussion the explanation referred to. It is as follows:

"In the pipe E F suppose the body M is placed. It may be a bubble, a piece of cork, a closed can—anything displacing a certain bulk of water and of a weight so small that it may be disregarded. Suppose, first, that the body M is attached to the pipe and thus prevented from rising. Then the pressure on a plane x y across the mouth of the pipe will be as great from the interior as from the exterior, notwithstanding the volume of water displaced by the body M. We are so accustomed to accept this fact, which the old text books on physics used to call the hydrostatic paradox, that we sometimes forget the reasons which lie behind it. Why is the downward pressure on the plane x y not lessened by the weight of the water which M displaces? Because the body M is buoyed upward by a force equal to this weight, that is to say, it exerts a reacting force downward upon the water of this amount, and thus just offsets the weight of the water which it displaces.

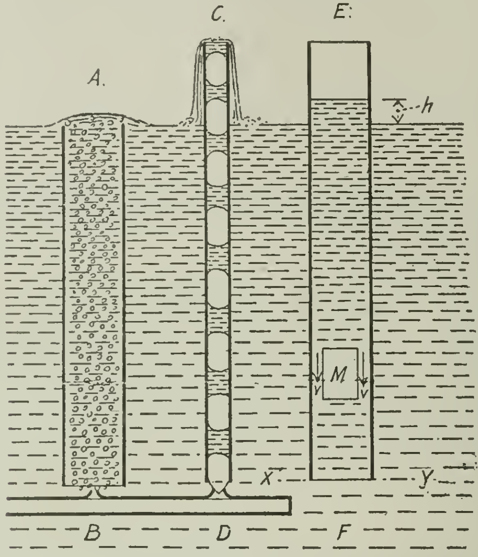

Fig. 11. Diagrams Illustrating Action of Air Lift Pump.

"Evidently when the conditions of the case are altered and the body M is allowed to ascend, it can no longer exert a lifting force upon the pipe, neither can it exert a reaction downward upon the water, except as friction and inertia retard its upward movement. Thus the total pressure downward on the plane x y will equal merely the weight of the water in the pipe and will be less than the pressure due to the head by the weight of water displaced by M.

"A very neat demonstration of the theory of the air-lift pump is sent to us by Prof. Elmo G. Harris, of the University of Missouri School of Mines. When the body M rises in the pipe by virtue of its specific gravity, the water in the pipe must flow down past the body with a velocity which we will call v. Where is the head to create this velocity?

Let O=volume of body.
S=distance through which body rises in a given time.
W=weight of unit volume of water.
A=area of cross-section of pipe.

"The buoyancy of the body=W O, and in rising a distance S it does work=W O S, which work is found in the downward velocity v of the water past the body (provided the water cannot rise so high as to flow over the top of the pipe). Then

$$W\ O\ S = W\ A\ S \frac{v^2}{2g}$$

$$\frac{v^2}{2g} = h = \frac{O}{A}$$

"That is to say, the head which causes the flow down past the body M, and which measures the rise of water in the pipe, equals the volume of the body divided by the area of cross-section of the pipe.

"If any of our readers still fail to understand how bubbles of air rising through a pipe can raise the water in it, let them consider the reverse case and suppose iron weights dropped through the water. It is evident enough here that the greater the size of the weight, the more will it tend to force the water down with it as it falls through the pipe; and the smaller the pipe, the more contracted the passage for the water upward past the falling weight. The same law which applies to the bodies heavier than water applies to these which are lighter."

The explanation of Mr. Hecht as to recent rising static water levels at Oak Park since the sale of the Austin end of the plant, and the, therefore, reduced pumpage, is undoubtedly correct.

The tendency of the static ground water level to rise and fall with variations in the pumpage covering a considerable period has been noticed at numerous places.

It has often been noted that in operating a gang of wells, one or more of them may show a tendency to flow irregularly One or two of the wells at Oak Park thus deliver the water in gushes, flowing with great force for a period of from twenty to forty seconds, then dribbling away, and ceasing to flow altogether for a like period. Measurements of flow seem to indicate that they deliver fully as much water as their more steady flowing neighbors, but quite probably at a reduced efficiency. This action is spoken of by Mr. Hecht, and also by Mr. Hedrick; it should not, however, be confused with the formation of piston like layers, specified by Dr. Pohle, which is quite another matter.

Mr. Spurling gives some interesting matter about the operation of a deep well steam pump at the Hawthorne plant of the Western Electric Company, and a comparison of same with a pump of the La Grange type, operated by electricity. According to his figures the steam pump is consuming 165 lbs. of steam. per H. P. hour. corresponding to a steam duty of 12 million foot pounds. His figures show that with electricity at 2c per kw. hour, a pump of the La Grange type would show about 40% saving. This saving could quite possibly be further increased by substituting a high speed steam engine for the electric motor and driving the pump with a twisted belt. With 50% pump efficiency, 95% belt efficiency, and

90% engine efficiency, the overall efficiency would thus be about 43%. As the unit is small an engine water consumption of 30 lbs. per H. P. hour could perhaps not be bettered. This water rate, with allowance as above for losses, would indicate a steam consumption of 70 lbs. water H. P. hour, corresponding to a steam duty of 28 million foot pounds, a fuel economy nearly 60% under the above steam pump referred to. Based upon 56% the reported overall efficiency of the vertical shaft centrifugal installed at the Pabst Brewery, Milwaukee, that installation is capable of very creditable duty. As both quantity and lift considerably exceed the Hawthorne conditions, a higher engine economy is practicable. It is not unreasonable to expect an engine water consumption of 22 lbs. per I. H. P. hour corresponding with correction for overall efficiency mentioned, to 39 lbs. of steam per water H. P. hour, which is equal to a steam duty of 50 million foot pounds. The actual duty at La Grange is purely speculative at this time, but probably does not differ materially from the following:

Pump efficiency	50%
Motor efficiency	85%
Line efficiency	90%
Generator efficiency	90%
Total	34.5%

As the electric current at Maywood is being generated by a turbine of good size, the electric consumption of the pump being but a small fraction of the total power generated, it is not unreasonable to assume a turbine steam consumption of 16 lbs. per H. P. hour, corresponding with allowance for transmission losses of 46.5 lbs. of steam per water H. P. hour, giving a steam duty for the pump at La Grange of 42 million foot pounds.

The question as to the best type of plant to adopt is always governed by the local circumstances. There are few cases where electric power can be purchased and successfully compete with steam, particularly if a steam plant is already available.

Where several scattered wells must be operated electricity is of advantage in that the power can all be generated at one place and transmitted at small loss for considerable distances.

Apart from the efficiency of the pumping devices, there is a reason at La Grange for operating the pump electrically. The generating station at Maywood supplies several electric lighting plants, and will ultimately supply several city water works systems. The advantage therefore of using electricity in pumping the wells is obvious.

As has been brought out in the discussion, the wear upon bearings in high speed pumps is a consideration which should receive careful thought. Such evidence as we have indicates that with clear water the question of wear in properly designed machines is not of serious moment. Prof. Mead cites two instances that bear upon this point, and the experience at La Grange, so far as it has gone, has been entirely satisfactory. One of the units has been in operation for about eight months without being taken out of the well, and without giving signs of distress from any cause whatever. When first placed in operation the bearings were given a small amount of oil through pipes provided for the purpose. Lately no oil has been used, the water being apparently sufficient for the purpose.

This seems to be in accord with experience elsewhere with this type of machinery.

It is understood that the Wood Propeller Pump has been applied in some situations where much difficulty was experienced with the bearings in water containing sand or grit, and to overcome this difficulty Mr. Wood has designed a special sponge packed bearing to protect the running surfaces. In the pumping of such waters there is little doubt but that any high speed pump will give more or less trouble, but fortunately in the pumping of deep well waters usually a clear water only has to be handled.

Mr. Hedrick has presented some interesting data, but he has apparently drawn some conclusions that do not seem to the writer to be warranted by the data that he presents. In the opinion of the writer, it is questionable whether even an approximate measurement of the air supply can be secured by a discharge through an orifice under so small a difference as one pound drop in pressure, with the ordinary means for making the observations. In a problem involving so many variables as that of the air-lift it is a difficult matter to draw deductions of general application without special facilities for testing, and the observation of results through some considerable range of each of the various factors. The experimental engineering department of our Universities are particularly fitted to do this work, and the profession will watch with interest and profit the experiments upon the air-lift that Prof. Mead has in contemplation at Madison.

THE DETERMINATION OF TELEPHONE RATES FOR LARGE EXCHANGES.

By Wm. H. Crumb

Presented October 11, 1907

The object of this paper is to point out some of the many questions which must be given careful consideration in order to properly establish equitable rates for large telephone exchanges, and makes no pretense of a suggestion as to what the particular rates should be, as such a determination is only possible after a careful consideration of all of the questions mentioned for any particular case to which they may be applied. Much of the information and particularly the charts and curves herewith contained were included in a report made by a special commission composed of Prof. Dugald C. Jackson, Dr. George W. Wilder and the author, selected by the city of Chicago to investigate matters pertaining to the telephone situation in this city.

The art of communicating by telephone is one of the most useful economic agencies devised by man, the development of which imposes a great duty upon any who undertake the furnishing of telephone service; therefore it is the duty of any firm or corporation organized for the purpose of furnishing telephone service in any community, and especially in a large city, to thoroughly develop the field in which they operate and supply good telephone service at reasonable rates. This duty involves a problem in many respects more complex than that of any other public utility corporation, and is partially caused by the personal element of the telephone user, partially by the relatively large number of classes of service which the telephone company must offer to its patrons for the purpose of fully developing its service, and partially by the intangible character of the electric medium with which the telephone business is carried on, the delicacy of the apparatus used and the wide difference in the manner and extent of the use of the apparatus by the varoius subscribers.

Telephone service contemplates the furnishing of facilities and setting up of electrical connections so that a person from any subscriber's station may communicate with or receive communications from a person at any other subscriber's station which may be connected to the system. The successful and satisfactory accomplishment of this depends upon many manual, mechanical and electrical operations, over some of which the telephone company has no control.

The demand for telephone service is very extensive and varied, and the company supplying it must be prepared to take care of the requirements of a range of patrons as wide as the range of the city itself, including the largest business organizations, hotels, newspapers, professional men, small business houses and residences of all classes. It must provide apparatus for the service of each class of patrons which will enable it to furnish service to each subscriber at an appropriate price within his means. It is desirable that the prices be graded so that the large user shall not pay less than his fair share of the expense for maintaining the telephone and remunerating the company for its investment; and equally so that the small user may get his service at a price which is within his means and yet is reasonably remunerative to the company for its outlay. The great problem which confronts all telephone companies of today is that of supplying a good quality of telephone service to the small user at a price which he can afford to pay and still leave a fair margin of profit to the company.

It must be assumed that any organization engaged in supplying telephone service has entered into that business with the primary object of a profitable investment for capital, and rates must be fixed and charges made with this point always in view. No company engaged in such a beneficial undertaking as this should be wrongly guided or compelled, either of itself or through legislative regulation, to adopt or put into force rates which will not insure a reasonable profit, for by so doing the development of this great and useful industry will be seriously retarded, and its benefits denied to those who are entitled to it.

In order to give the best possible telephone service the following features must be maintained at the highest possible standard:

The telephone plant should be engineered and constructed along broad lines, with ample facilities for handling the business and taking care of future growth, and should at all times be well maintained in first class working order.

There should be provided suitable means for quickly and accurately connecting and disconnecting subscribers' lines, also for signalling the subscriber desired without the knowledge of any other subscriber.

All lines should be free from inductive disturbances and of sufficient carrying capacity to provide for a high standard of transmission.

The speech transmitting and receiving devices should be of the best quality and carefully maintained.

The number of cut-offs which interrupt communications, the number of busy reports and other unavailing calls, and all interferences with conversations between subscribers should be reduced to a minimum.

The work required of subscribers should be reduced to a minimum.

All of the plant employed in producing service should be under the control of one corporation or organization.

The company furnishing service should provide courteous treatment to all of its subscribers, and should promptly and fully follow up and satisfactorily adjust all complaints.

An accurate directory of subscribers telephone numbers should be provided.

There are two general methods which have been adopted by telephone companies of charging for telephone service, namely; the flat rate method and the measured service method.

The term flat rate ordinarily means the manner of charging for service which consists of a fixed price per year for furnishing the subscriber with a telephone instrument in his place of business or residence and a suitable line or lines and means of connecting, so that he may converse with other subscribers at will. This method is a survival of the idea that the telephone company rents apparatus and telephone lines, and is based upon the theory that the cost of providing service to any subscriber to a particular class of service will be very nearly equal to the average cost in that class of service. When flat rates are charged the telephone subscribers are ordinarily divided into two classes of service, business subscribers and residence subscribers. These classes may be sub-divided by placing 2, 3, 4 or more subscribers upon a party line, which sub-divisions are made on the basis of differences in the amount of equipment required for each subscriber. All subscribers to flat rate service are authorized to make as frequent use of the telephone as their requirements or convenience warrants, and all subscribers to the same class of service are presumed to pay the same price. The warrant for this equality in price charged subscribers who may make use of their telephones in widely different degrees lies only in an assumption that the expense of the service is almost altogether a matter of providing lines and apparatus, and that the cost of providing each subscriber's service is practically the same for all subscribers in that particular class. The greatest range of rates that it is possible to make with a flat rate arrangement is relatively small. The difference between the highest paying flat rate subscriber and the lowest paying flat rate subscriber being relatively small tends to retard telephone development and prevent its general use. Assuming that the total receipts of the telephone company operating under flat rates are sufficient to pay the cost of operating and maintaining the service and produce a reasonable profit on the investment, it is evident on account of the very unequal use of the service by the different subscribers that the small users manifestly pay more than their service requires, while the large users, who keep their telephones constantly busy, receive a service of much greater value and more expensive to the company than is justified by the annual amount which they pay. The large use of busy flat rate lines interferes with the traffic of the small users by keeping their lines so busy that the small users are unable to conveniently get into communication with them, thus causing unavailing calls which are expensive to the company and annoying to the subscribers.

The term measured rate service ordinarily means service which is carried on upon the assumption that the telephone company is organized for the purpose of giving telephone service as distinguished from the renting of instruments. It is of course obvious that the company must furnish its subscribers with suitable telephone instruments and lines and also provide the necessary equipment for making connections between subscribers' lines, which is made purely for the purpose of enabling subscribers to transmit messages between each other with the greatest practicable convenience and dispatch. It is the business of the telephone company to provide the means for the transmission of messages, and measured rates go upon the assumption that the telephone company should be paid for the performance of this specific service. Since it is necessary for the company to go to considerable expense to provide the subscriber with facilities for the transmission of messages, it is appropriate for the company making measured rate charges to exact a guarantee that there shall not be less than a fixed minimum number of messages, or that the rate paid shall not fall below a certain reasonable amount per annum. This amount usually includes the transmission of messages up to an appropriate number, over and above which an additional charge may properly be made per message. The ideal method of charging for telephone service is obviously to charge the subscriber in proportion to the service which he receives, and to make the charges to all subscribers as low as is consistent with the operation and maintenance of the property and the payment of a fair return on the money invested. The measured rate arrangement manifestly makes it possible to reduce prices to the small telephone user to the smallest possible annual charge, that is to a charge which is just sufficient to cover a reasonable interest and depreciation for the portion of the plant that must be set aside for the individual user (or the average of the users of his particular class) increased by an amount which is proportional to the actual number of messages transmitted from his telephone in a year. It is only by this arrangement that large city service may be extended to small business men and small residence and apartment dwellers, whose demand for service may not warrant them in paying more than $18.00 to $24.00 per year, and this sort of subscriber constitutes a remarkable proportion of the total telephone using population of a large city.

In all other lines of business where articles or service are sold, the selling price of each article or class of service is based upon the cost of producing the particular article or the class of service rendered. It is true that in some cases these items of cost are based upon averages, but they are usually determined from detailed knowledge in such a way that where averages are used cost prices are arrived at with considerable accuracy. Strange as it may seem telephone companies have made no successful efforts to arrive at the detailed costs of furnishing the different classes of service, and the problems relating to each class of service and the proper charges for different classes of service have not been worked out in a suitable manner. The telephone companies apparently have been so fully engaged in the extension of their business and the extension and improvement of their plants that they have not found men or time to work out the details of operating economies and the best methods of handling service of different classes of subscribers in the way railroads, traction companies, electric light companies and various other public utility corporations have been working out the details of economy relating to the processes of their operation. Records have not been kept in such detail nor in such manner as to afford appropriate data for fixing rates, and in every instance telephone rates seem to have been dictated by estimates based upon experience or the requirements of business expediency instead of being founded on a knowledge of the cost of producing different classes of service. Telephone companies seem to go on the belief that their business is satisfactory if the total receipts of a year's business show a profit and they have heretofore apparently neglected to consider more than superficially the essential question of whether the rates charged dealt fairly by the different classes of subscribers. It is an unfortunate condition in the telephone business that the telephone instrument should be generally adopted as the unit upon which telephone rates are based instead of the telephone message, the instrument being provided simply to enable the subscriber to transmit messages.

In order to determine the proper rates to charge for different classes of service it is necessary to first ascertain the cost of producing each class of service. This cost of production is made up of five principal items as follows: (1) Plant investment. (2) Operating expenses. (3) Maintenance expenses. (4) General expenses. (5) Depreciation and insurance.

The object of constructing a telephone plant is to provide facilities for furnishing telephone service, and it must be assumed that when a plant is constructed it is to be built with the idea of fully developing the telephone business in its particular locality, and in order to do this it is necessary to construct the plant in such a manner that various classes of service may be furnished in order to fully meet the requirements of the various classes of telephone users. A telephone plant in a large city usually consists of a group of central offices, each one of which is connected to all the others by a system of trunk lines and radiating from each are the lines extending to the various subscribers premises. Each central offiice is provided with suitable switchboards so that connections between subscribers lines can be quickly made. The amount of capital necessary to invest in the construction of a telephone exchange necessarily depends largely upon the local conditions and also upon the requirements which may be placed upon the company by city regulations. Some of the principal features which go to determine cost of construction are as follows: Number and location of central offices. Price of real estate. Average length of subscribers lines. Character of public improvements. Municipal requirements. Traffic requirements. Provisions for growth and development of the business.

It is the object of the telephone engineer in designing a telephone system to so plan the plant that it may be constructed in the most economical manner to fully meet the present and future telephone requirements of the locality in which it is built. One of the first and most important matters to be given consideration is the number and location of central offices. It is impracticable with our present method of manual telephone operation to connect more than 10 to 12 thousand subscribers lines to a single multiple switchboard, so that the maximum grouping of subscribers lines on one board is thus limited to that number. It is possible, however, to group two or more switchboards on the same premises so that centers of distribution for an unlimited number of subscribers may be located at will. The most economical location of central offices is that which will provide for the shortest average length of subscribers line and still limit the number of central offices so that the percentage of trunk calls will be reduced to a minimum and the investment in trunking plant likewise reduced to a minimum. The price of real estate has much to do with determining the location of central offices, and usually is a very considerable factor in the construction cost of all large exchanges. Character of public improvements, principally that of street paving, is responsible for a great deal of the expense of constructing telephone plants, as in all large cities considerable amounts of underground conduits have to be installed, and it is of course much more expensive to lay these in paved streets than in unpaved ones. Municipal requirements also influence construction costs considerably, the principal requirement being that which compels telephone companies to place all wires within certain localities in underground conduits, and also those which make it necessary for a company to replace portions of its aerial plant with underground conduits and cables. The small telephone user may be provided with ample facilities for handling his telephone traffic by means of a party line, whereby several subscribers may be connected to the same line, the number being directly dependent upon the in and out traffic of the total number of subscribers connected to the line. The subscriber of larger use requires a single line and this is graded up to the largest user with a private branch exchange and several trunk lines, all of which are directly in proportion to the amount of traffic which the telephone user has.

It would indeed be a simple problem for the telephone engineer to design an economical telephone plant for any given number of subscribers whose locations and traffic requirements were known and would remain permanent, but the telephone business is developing and extending at such a remarkably rapid rate that it is necessary in designing a telephone plant to look far into the future in order that the work done now may become an economical part of the plant years in advance. The history of the telephone business has been so short that no well defined laws of development have been arrived at. Yet experience teaches that past estimates of future development have been very much underestimated and that in the future we have reason to look forward to even greater development than that of the past. Less than fifteen years ago there was no

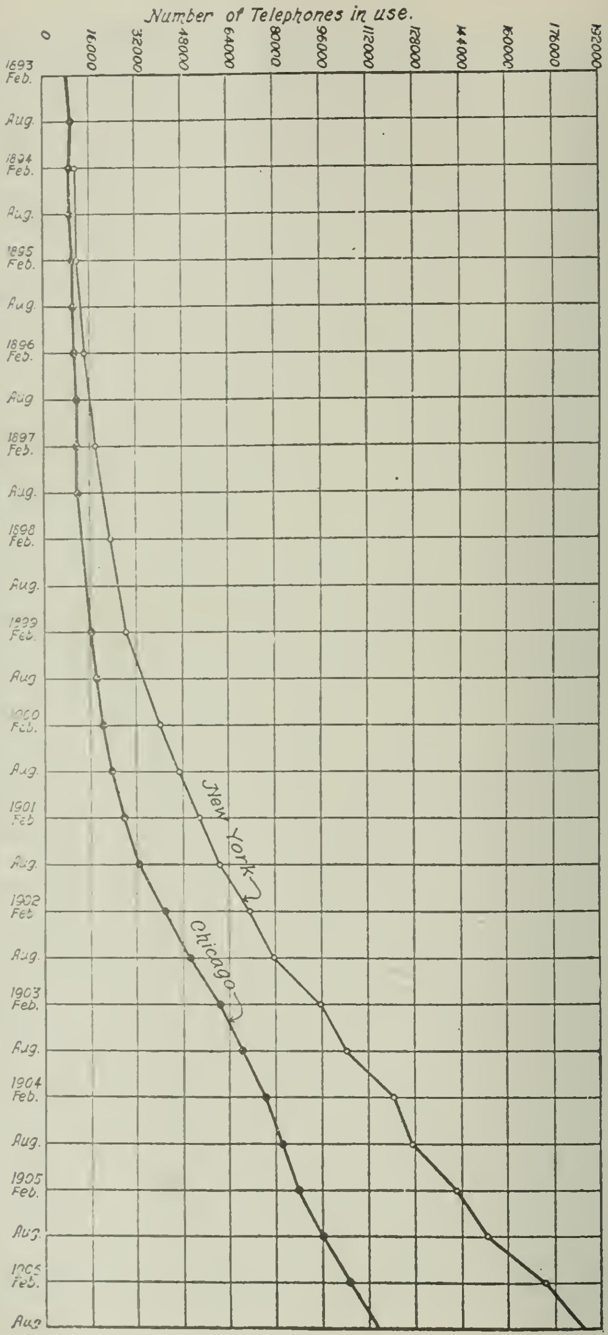

Fig. No. 1. Showing the growth in number of telephones in use in Chicago and New York.

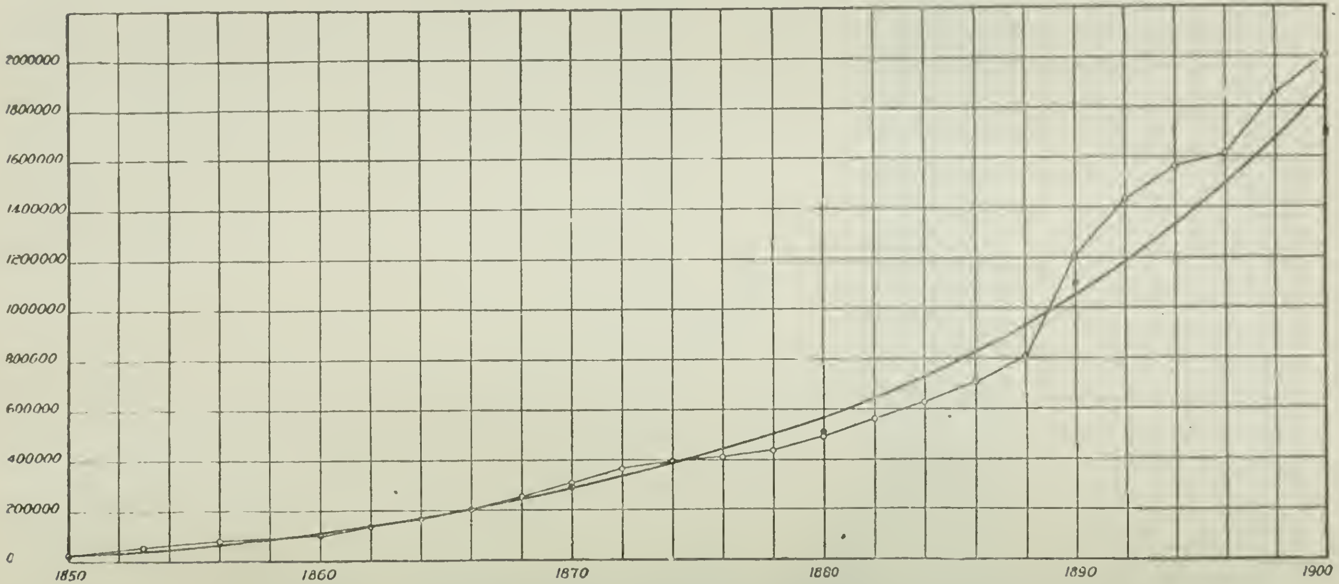

Fig. No. 2. Showing population of Chicago in the past, taken from school census and federal census reports.

telephone exchange system with as many as 10,000 subscribers served by the system; at that time the number of telephones in Chicago was considerably under 10,000. Only seven years ago there were less than 25,000 telephones in Chicago, and at about that time the present tremendous rate of growth in the number of telephones began, the average increase during the last five years being at the rate of approximately 20,000 per year. A similar increase in the growth of the number of telephones began in New York City a couple of years earlier.

In Fig. 1 is shown the growth and number of telephones in use in Chicago and New York from 1893 to August, 1906. This rapid

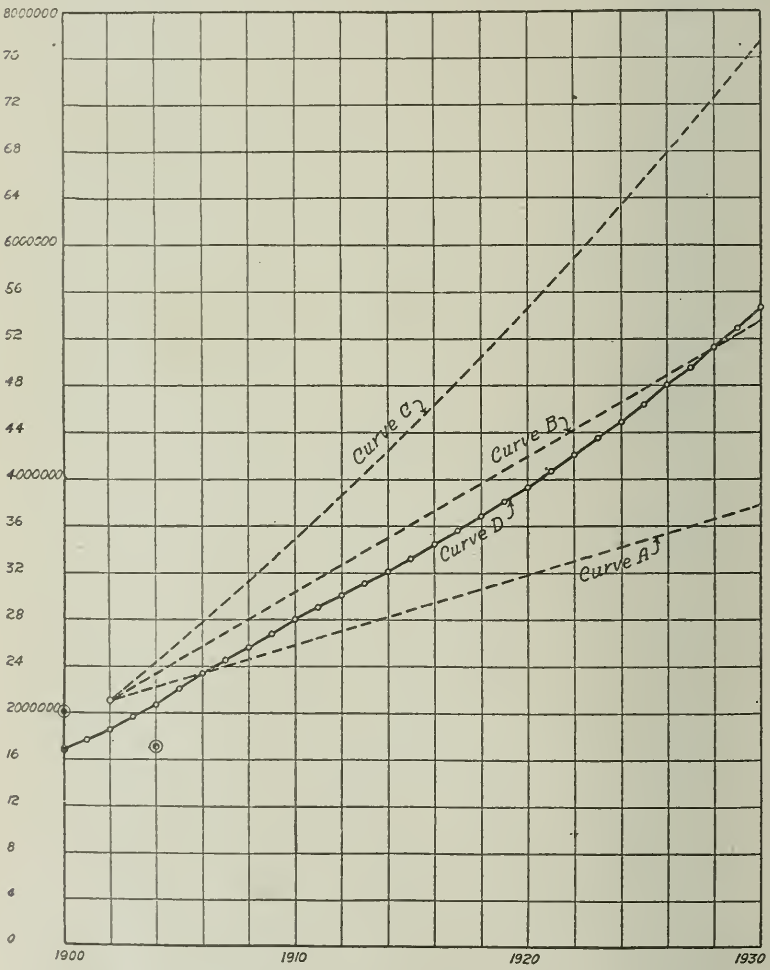

Fig. No. 3. Showing probable future growth in population of Chicago.

growth demands a large idle investment in plant cost, as in most cases it is more economical, and in others absolutely necessary, to make plant additions in large units to provide facilities which remain idle until the growth of the plant has made ther use necessary, at which time large additional investment must be made.

In designing a telephone plant which will economically meet the requirements for future service, it is necessary for the engineer to give careful consideration to the past and probable future growth in population of the city, and of the past and probable future percentage of telephone development in the city. Fig. 2 and Fig. 3 show the growth of population in the city of Chicago in the past and the estimated future growth. The population given by the United States census at the end of each decade is shown by the black dots on Fig. 2; the open circles show the population given by the school census reports. The full curved line indicates the average growth of the city and illustrates the tremendous rate at which the city has been growing during the past decade, and that there is no tendency toward a falling off in this growth. Curves A, B and C in Fig. 3 show estimates of the city's future population as given by Mr. Bion J. Arnold in his report on the traction situation, starting with an assumption of 2,100,000 inhabitants in 1902. Curve D shows an estimate of future population made by City Statistician Grosser. Mr. Arnold's average curve (Curve B) and Mr. Grosser's curve cross each other at the year 1928, and the indication of the curves is that the population of the city will be not far from 5,000,000 inhabitants twenty years hence. Curve A is Mr. Arnold's minimum estimate and Curve C is his maximum estimate of future growth in population of the city.

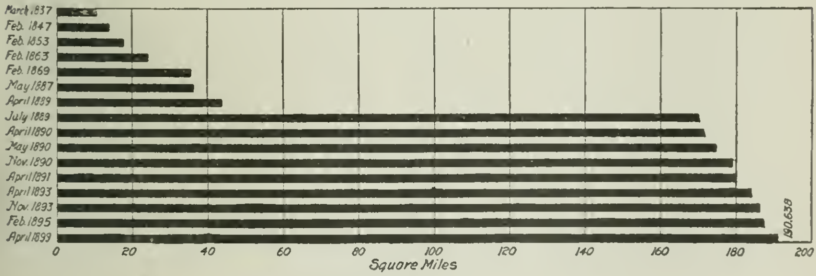

Fig. No. 4. Showing growth of area of the City of Chicago.

In Fig. 4 is shown the way in which the area of the city of Chicago has been growing, from which it will be seen that from 1889 to 1899 the area of the city has increased practically twenty square miles, which is at the rate of two square miles per annum; and it is very probable that future additions to the area of the city may be expected from time to time during the next several years.

The increase and percentage of telephone development in Chicago since 1894, is shown in Fig. 5. By percentage of development, is meant the number of telephones in use for each 100 inhabitants. It will be seen that this percentage has increased at a very rapid rate; and it is to be expected that this development will expand with improved and cheaper service until there are at least 10 telephones to every 100 inhabitants and that the telephone development which should be planned on to occur in the city of Chicago at the end of the next twenty years should be made with a view to providing a system with as many as 500,000 telephones and perhaps 600,000 telephones; 400,000 telephones is too low an estimate to be reasonable, especially in consideration of the fact that a first class and cheaper service is likely to increase the percentage of development beyond 10 per cent, and may increase that deevlopment to a point where as many as 15 telephones may be needed for each 100 inhabitants.

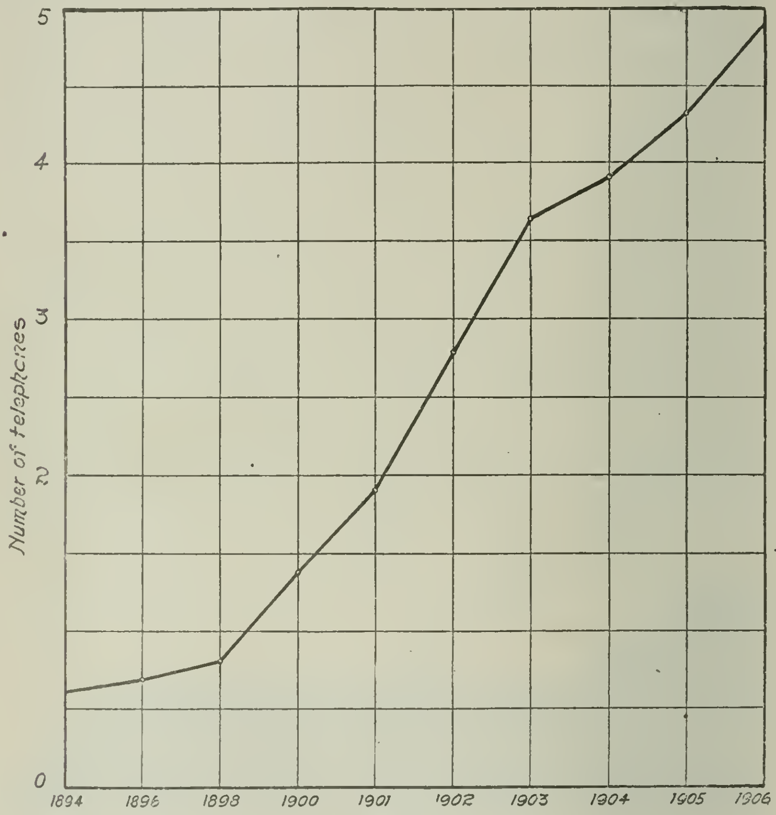

Fig. No. 5. Showing number of telephones in use in Chicago for each one hundred inhabitants.

In Fig. 6 is shown the change in the average price paid each year per telephone and the average number of telephones in use during the year in the Chicago city exchanges for the past ten years, while

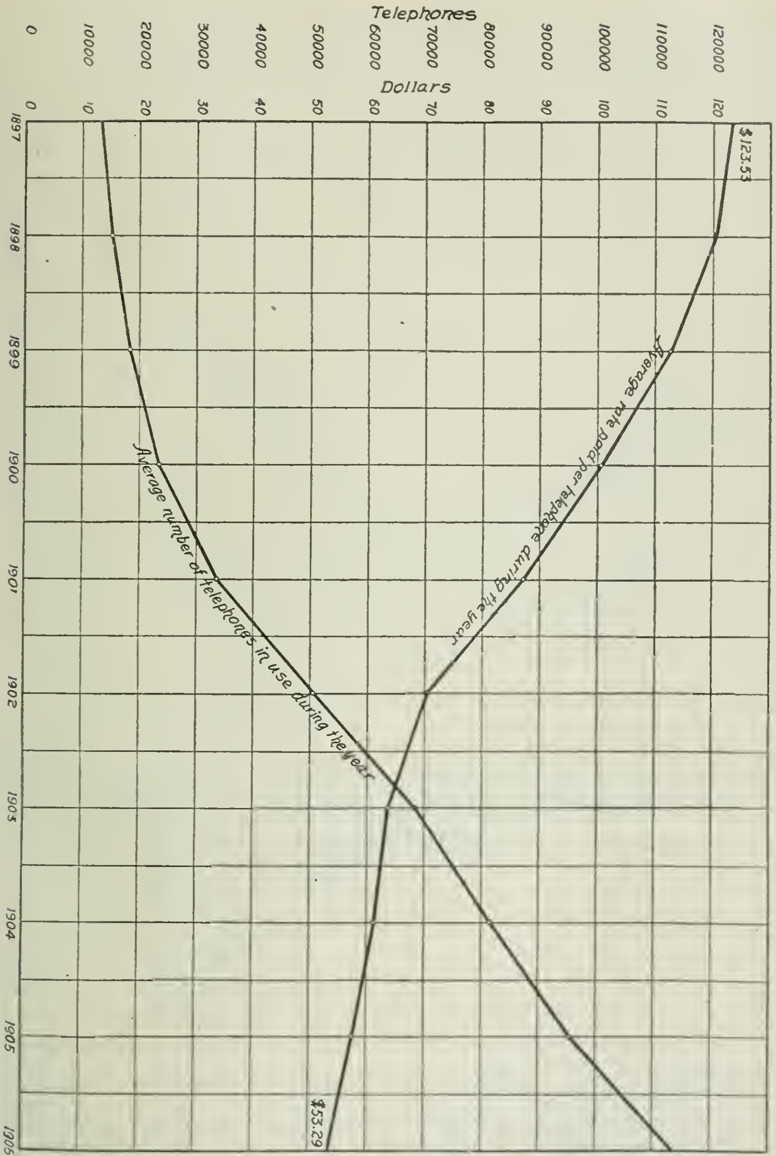

Fig. No. 6. Showing the change in the average price paid each year per telephone in Chicago for the last ten years.

Fig. 7 shows the same information for the neighborhood exchange districts. These charts illustrate the way in which telephone development has heretofore increased as the price per telephone has decreased. A consideration of the manner of charging must be made with due provision for the tremendous number of telephones that an operating company would be called upon to provide within a few years.

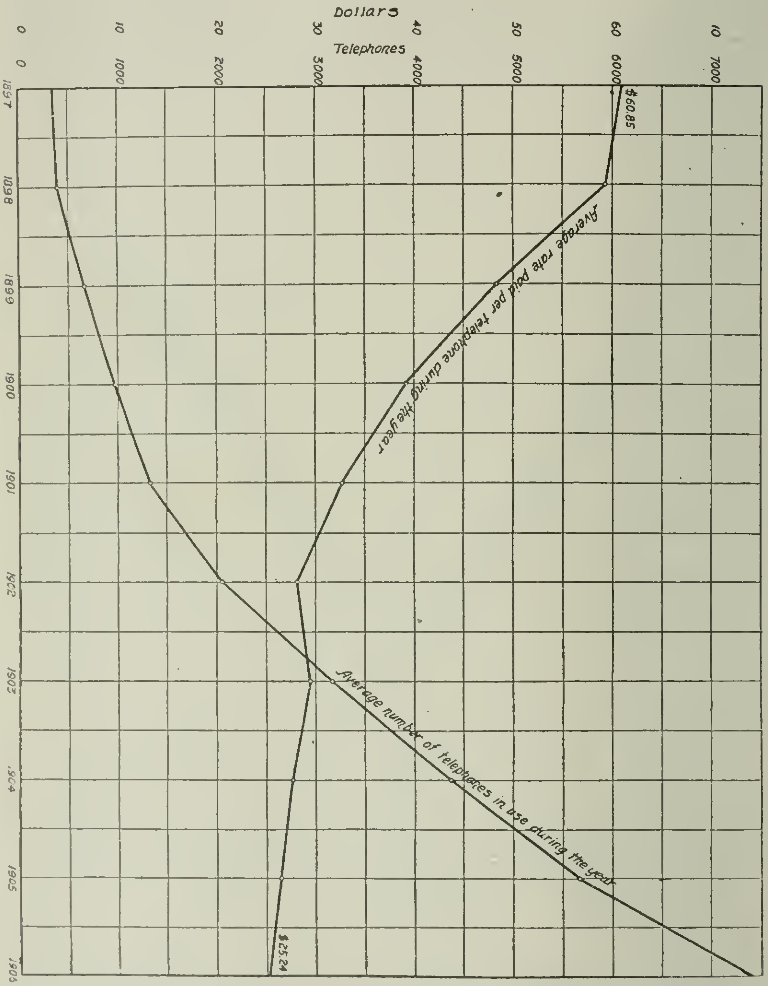

Fig. No. 7. Showing the change in the average price paid per year each year per telephone in the neighborhood exchange districts for the last ten years.

The growth of the different classes of service since August, 1901, is shown in Fig. 8. It will be observed that during this period, measured rate telephones have increased in number very much more rapidly than the flat rate telephones, 10 party line telephones and private branch exchange telephones belonging to the measured rate class. The flat rate business and residence telephones have not increased in a very large degree. As is shown in this chart the great growth in the number of telephones operated by the Chicago Telephone company has been due to the introduction of the measured service method of charging for telephones. The decrease in the average price paid per telephone from 1897 to 1906 is shown in Fig. 6, this average having decreased from $123.53 in 1897 to $53.29 in 1906. This decrease in average price was made possible by the introduction of the measured rate, under which the operating and maintenance expenses are less than under the flat rate, because the subscribers restrict the use of the telephones to their actual needs and the lower prices make it possible for people whose requirements for telephone service are limited to provide themselves with such facilities.

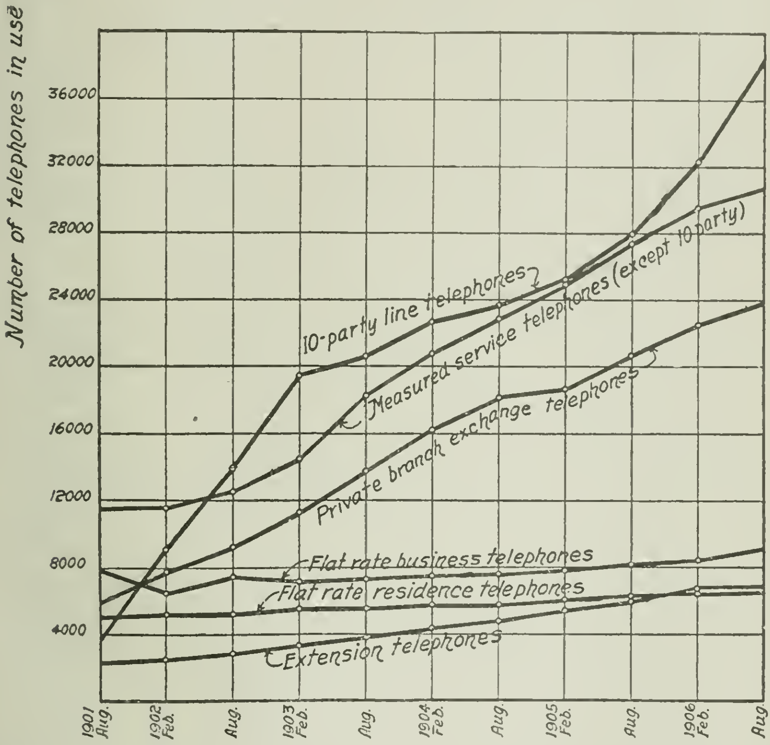

Fig. No. 8. Showing the growth of the different classes of service in the Chicago exchange district since August 1901.

The cost of operating a telephone plant is directly proportional to the traffic and not proportional to the number of telephones in service as is so often erroneously presumed. This error has been made by considering the telephone as the unit in the determination of costs instead of the message. In order to provide good telephone service good operating conditions should be maintained, which means that in addition to a well constructed plant the various subscribers should be provided with a suitable number of lines to fully meet the demands of their service. Under the flat rate method of charging, subscribers, in order to economize their telephone bills, often restrict themselves with regard to the facilities which they contract for so that their lines are very much overloaded with traffic, thereby causing a large number of busy reports which are annoying to the subscriber and expensive to the company. If the measured rate service is established the charge per message should be made so that the telephone company will receive a reasonable profit on its investment without overloading its lines with traffic, and so that the subscribers can provide themselves, without additional cost per message, with additional facilities as their traffic increases beyond the fair working capacity of the lines they have contracted for .

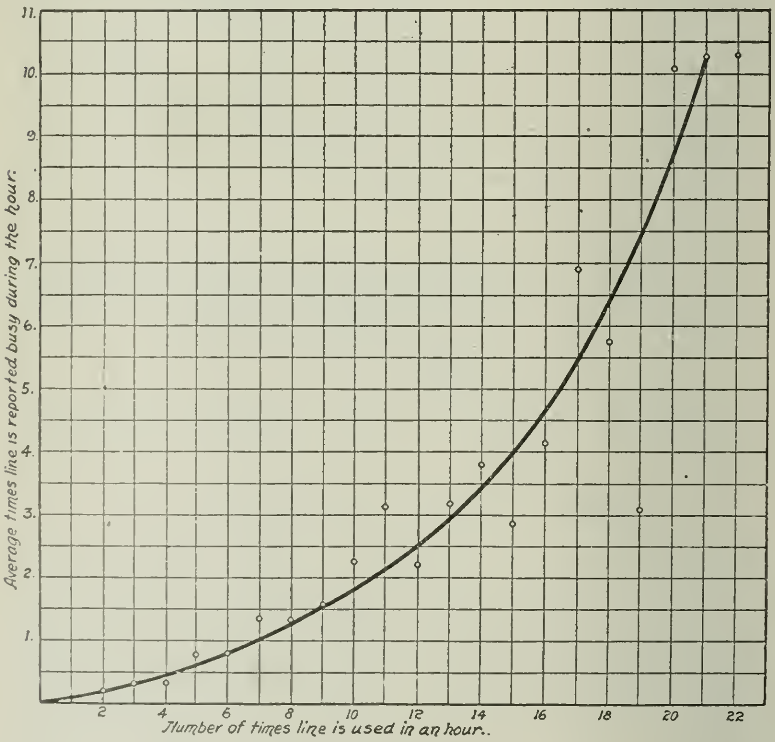

Fig. No. 9. Record of observations made for the purpose of learning the relation between the number of times a line is used in an hour and the number of times the line is reported busy during the hour.

In Fig. 9 is shown a record of observations made for the purpose of learning the relation between the number of times a line is used in an hour and the number of times the line is reported busy during the hour. By the phrase "number of times a line is used in an hour" is meant the exact number of outgoing and incoming messages which pass over the line in the hour. This curve is made up from a large number of observations and is believed to be fairly representative of conditions. It will be observed that if a line is used 11 times an hour it may be expected to be reported busy at least twice during the hour to calling subscribers who desire to communicate with that line; but, if it is used 21 times an hour it may be expected to be reported busy no less than 10 times. This plainly shows that the unavailing calls increase at a tremendous rate as the load on a telephone line increases. The fact that flat rate subscribers have a tendency toward the overloading of their lines, thus causing an undue number of busy reports, is a very substantial reason why it costs more per message to produce flat rate telephone service than measured rate.

There is indicated in Fig. 10 the way the total number of calls emanating from telephones in the Chicago exchange district have increased since 1893. For the purpose of these charts a call is counted each time a subscriber takes his receiver from the hook and his signal is answered by the operator. Of the total number of calls on each week day, which at present average nearly a million in the Chicago exchange district, about one-third of the traffic as now handled constitute unavailing calls, that is calls made by subscribers which prove to be futile efforts and do not mature into messages because the line called for is found to be busy, or the called for subscriber fails to answer his telephone, or any of the various other fertile reasons for failure of a call to be completed into a message. Each of these calls means cost for the operations performed. To bring about good and cheap telephone service it is necessary to reduce these unavailing calls to the lowest possible number and especially to reduce the frequency, called for lines are found to be busy. Such busy reports now constitute in Chicago about one-half of the total unavailing calls, the average being 16 per cent of the total number of calls, and this is in a large degree due to the overuse of flat rate telephones; but with a measured service the telephone subscriber restricts his messages to his business or social necessities and is able to provide himself with facilities enough to handle his business without overloading his line or lines. Frivolous and useless messages are largely cut off by the introduction of measured rates, since even a small charge per message acts as a marked deterrent to the needless use of the telephone. This is illustrated by the line representing the average number of daily calls made from each telephone shown by Fig. 10. The number of telephones has been steadily increasing, as shown in Fig. 1, and the total number of calls per day has also been steadily increasing, but the average number of daily calls emanating from the individual telephones began to decrease in 1899 and has decreased from an average approximating 16 calls per

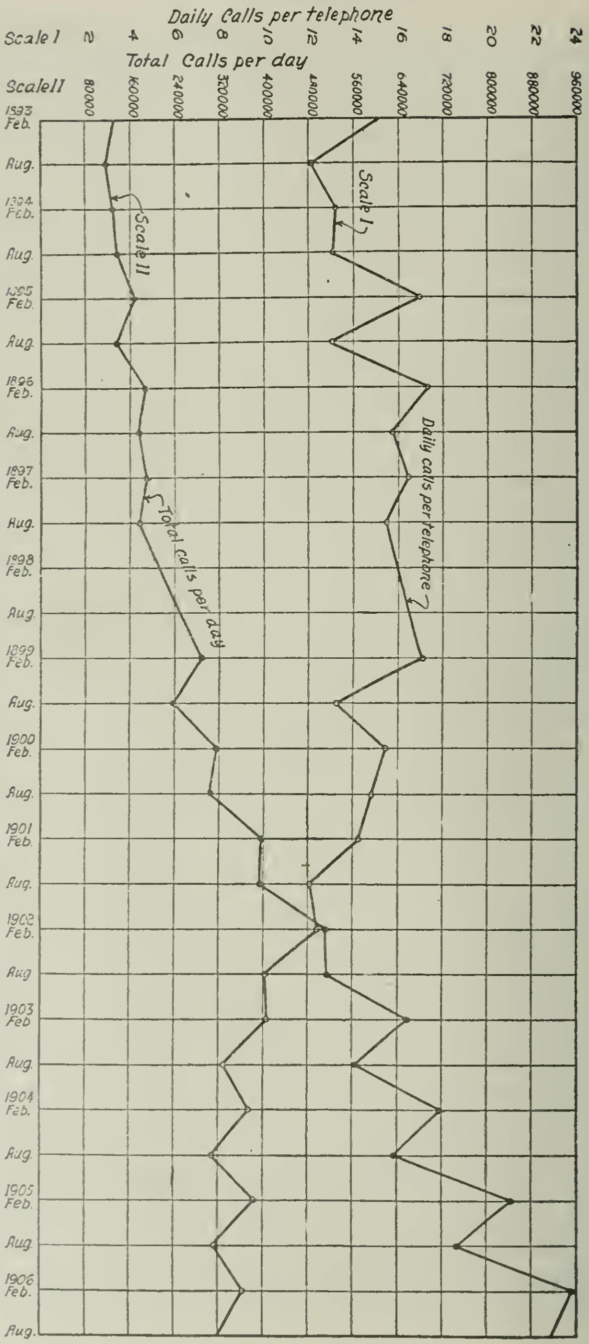

Fig. No. 10. Showing the calls per day in the Chicago exchange district and the number of daily calls per telephone.

telephone per day to an average approximating 9 calls per telephone per day. The time that this decrease began is concurrent with the introduction of measured rates, and during the four years while measured rates were coming into vogue the average daily calls per telephone were steadily decreasing until now they have reached an apparent fixed value.

It is unfortunate that reliable data is not available whereby the exact cost per message of producing telephone service can be obtained. However, considering Fig. 6 in conjunction with Fig. 10 we observe that the decrease in the average price per telephone per year has been concurrent with a corresponding decrease in the average number of calls per telephone per day, and consequently the average number of calls per year. It has been this decrease in traffic per telephone that has made it possible for the telephone company to decrease its average rate per telephone. And, as has been pointed out, this decrease in traffic is due to the introduction of the measured rate basis of charging. While the average cost per telephone has decreased approximately 56 per cent during the period shown on Fig. 6, it would be interesting to know the decrease in the charge per message. Such data as is at hand shows clearly that the charge per message has been decreased and it is estimated that this decrease amounts to approximately 20 per cent, which illustrates that it is cheaper per message for the telephone company to produce service in large quantities than in small quantities.

It is a tradition in telephone circles that the service per telephone costs more as the number of telephones connected with the plant increases. As the number of telephones increases each subscriber has the opportunity to call upon more people by telephone, and the law of averages would indicate that the number of calls per day from each telephone should increase, thus making the service more expensive to the operating company, provided the service is flat rate service and unnecessary use of the telephone is not deterred by a measured rate charge. This condition seems to have worked out in practice. according to the statements of telephone companies at Cleveland. Indianapolis, and elsewhere, and flat rate service seems to increase in cost per telephone as the number of telephones attached to a system increases.

On the other hand, a different condition exists in connection with measured rate service. With the measured rate service the message is the unit instead of the rental of the instrument; and it is the message that the subscriber ought to pay for, because it is for the purpose of sending his messages that he provides himself with a telephone. With measured rate service, and a reasonable use of the telephone lines. the unavailing calls are reduced to a minimum. . The number of calls per telephone per day. apparently. are not inclined to increase as the system increases in extent. This is illustrated in Fig. 11 and Fig. 12; but the total number of messages handled increases approximately in proportion to the number of telephones. Under these conditions the ordinary laws regulating the difference

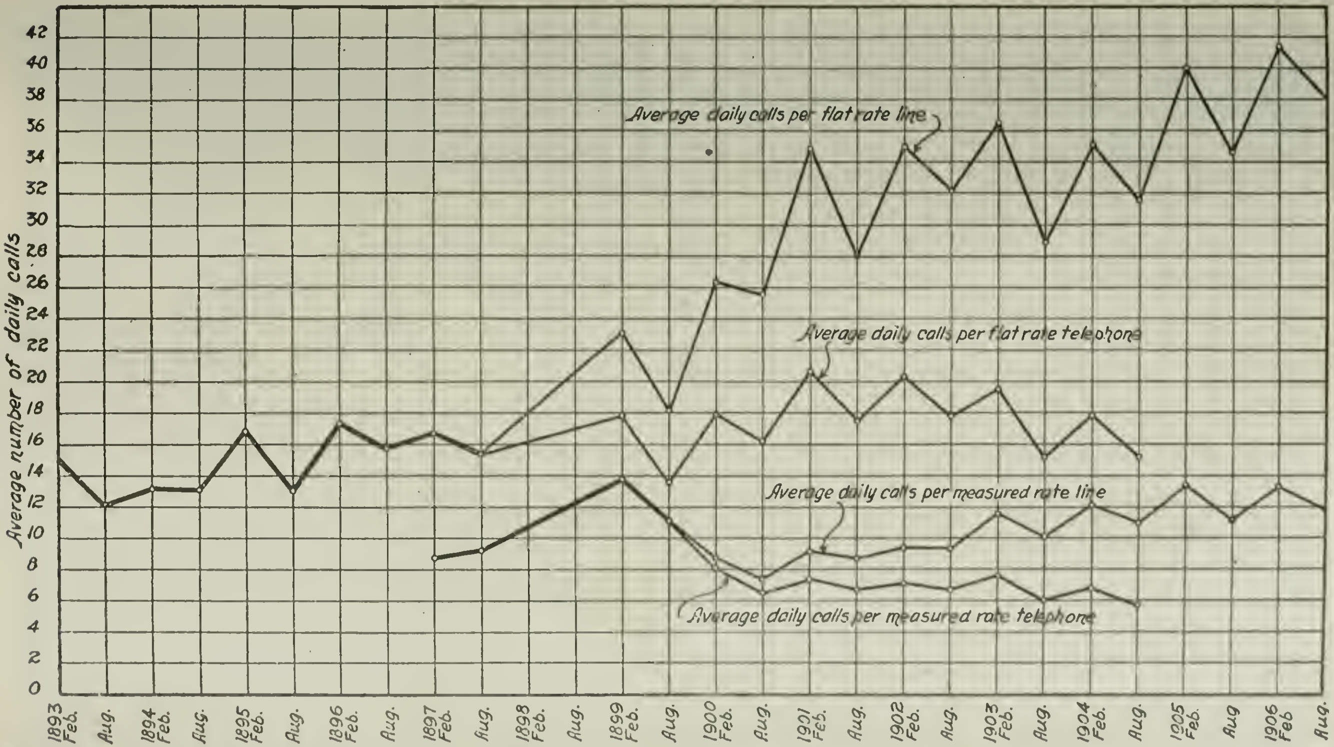

Fig. No. 11. Showing the average numbers of daily calls per line and per telephone on flat rate lines and measured rate lines in Chicago exchange district, excluding 10-party lines.

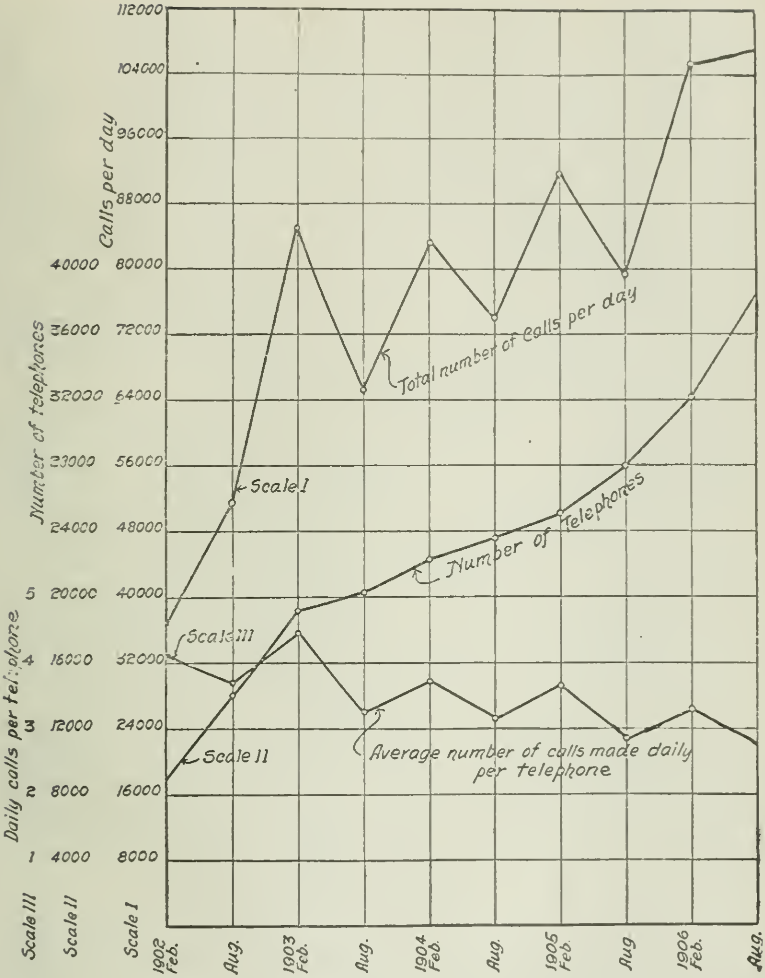

Fig. No. 12. Showing the number of 10-party line telephones, the number of calls per day originating therefrom, and the average number of calls made daily per telephone.

between the cost of producing articles in large and small quantities come into play, and the actual cost per message ought to decrease steadily. Since it is the messages that are paid for under the measured rate system and the actual cost per message ought to steadily decrease as the system enlarges, the average amount paid by each subscriber will decrease if the subscribers limit the use of their telephones to their actual needs and the telephone company is well managed.

The difference thus arising between flat rates and measured rates is very marked. The flat rate telephone user tends to increase his number of messages as the system enlarges, so that the average calls per day per telephone may be expected to increase and the proportion of unavailing calls also to increase. The consequence is that the company is forced to handle more calls per telephone as the system becomes larger, and the price per telephone has to increase under flat rate charges; while the subscribers limit the use of the telephone to their actual needs under measured rates and the number of calls per telephone does not have a tendency to increase as the system increases in size after it has reached a considerable development such as is now found in the city of Chicago. Under these conditions the principle of wholesale production makes it possible for the company to reduce its cost of operating per message and thereby reduce the average price charged the telephone subscribers.

The telephone hanging on the wall appeals to the average telephone subscriber as constituting the total expense to the company through the maintenance of the instrument and lines. The maintenance and the interest on the equipment does constitute a considerable expense to the company, but a great deal of the expense to the company is due to the actual cost of handling each message.

Moreover, the more calls that are made per line, the larger must be the switchboards provided by the company for making connections for communication between subscribers' lines, since each operating employe can only take care of a limited number of calls per day, and if the number of calls per telephone increases, each operating employe can take care of the requirements of fewer lines. As the operating employes are increased, the switchboards must be increased at large expense to afford additional operators' positions, and all of this increases the annual expense for telephone service. The deterrent of a small charge per message, varying from a nickel downwards depending upon the number of calls used per year is sufficient to overcome much of this difficulty and to reduce the telephone service to a fairly uniform and business-like basis.

There is another feature which relates to the question of relative use by flat rate and measured rate users of telephones. It is impracticable to connect all telephone subscribers in a great exchange system with a single office, and it becomes necessary to arrange means for transferring calls made by the lines in one office to the called-for subscribers' lines in other offices. This is ordinarily denominated "trunking" the calls between the offices, and it involves a double expense for operators, since one operator is required to receive the call of the subscriber at the originating office and another operator is required to complete the connection to the called subscriber's line in the second office. As the system increases in number of telephones the proportion of "trunked" calls is likely to increase. This is illustrated in connection with Fig. 13 which shows the way in which the "trunked" calls, marked "B calls" on the chart, increase as the service extends. This shows the daily number of "B calls" according to the "peg counts" of February and August for a number of years back, and it will be observed that the number of "B calls" consistently increased during this period. The illustration also shows the number of measured rate calls originating from subscribers' lines and the number of flat rate calls originating from subscribers' lines,

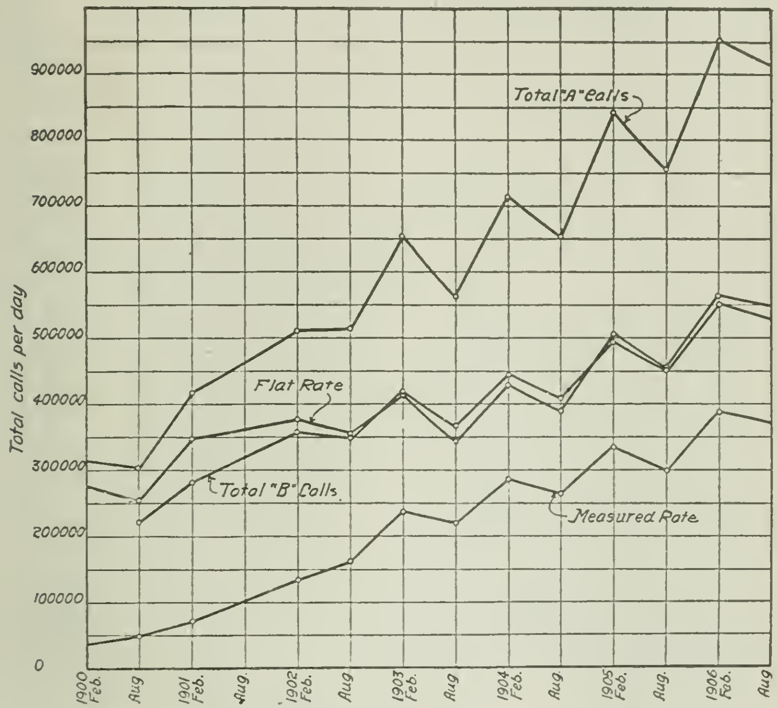

Fig. No. 13. Showing the way in which trunk calls (B calls) increase as the service extends.

and it will be observed that the number of flat rate calls has increased year by year at a rate approximately equal to the increase of calls from measured rate lines, although the number of flat rate lines has not been increasing as rapidly as the measured rate lines. Chart No. 13 also shows that the rate at which "B calls" or "trunked" calls increase corresponds more nearly to the rate at which the flat rate calls increase in number than to the rate at which the measured rate calls increase in number.

The indications that are afforded by Fig. 13 are likewise afforded by the series of load curves here given. A load curve is a curve showing the number of calls occurring within a telephone exchange during each hour of the day. Fig. 14 is load curve showing the sum of the calls obtained from the several exchange offices in the Chicago exchange district. The curves are shown as the total number of calls

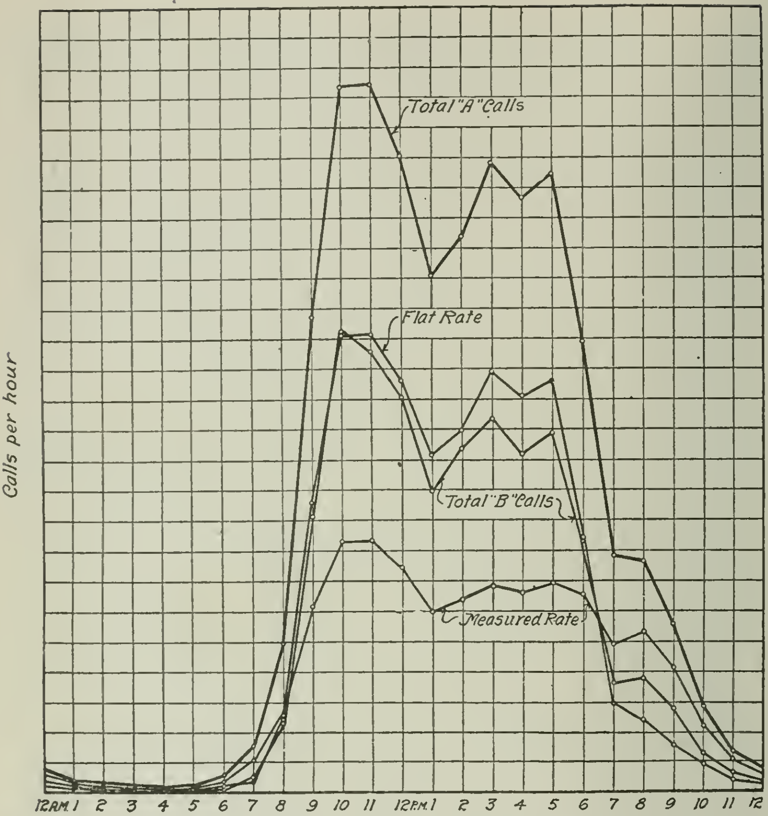

Fig. No. 14. Total load curve for Chicago exchange district August 3, 1906.

originating on all the subscribers' lines (marked "A" calls) on August 3, 1906, during each hour of the day, the total number of measured rate calls during each hour of the day, the total number of flat rate calls during each hour of the day, and the total number of "trunked" or "B calls" coming into all of the exchanges during each hour of the day. A point on each of these curves indicates the number of calls of the particular class during the corresponding hour of the day. The indication of "B calls" on the load curves for the several separate exchange offices, does not afford any means of telling from what sort of a line the original calls emanated because records of the trunked calls are only made at the receiving office, while the sending office (where the "B call" is not recorded) is the only one which could determine from what sort of a line a trunked call emanates. But the total load curve makes it possible to compare the total trunked calls with the total flat rate and total message rate calls, and it will be observed that the number of trunked calls corresponds closely to the number of flat rate calls. This is probably an indication that the greater proportion of the trunked calls come from flat rate lines, and that these lines are consequently causing more than a proportional share of the double expense of the trunked calls. A study of this question from the records of the Chicago Telephone company extending back over the period since the introduction of message rates in Chicago shows a similar indication in each year, namely, that the trunked calls correspond more closely to the flat rate calls, and that the flat rate lines apparently therefore should be properly charged with the larger proportion of the expense of the trunking service and maintaining the trunking plant.

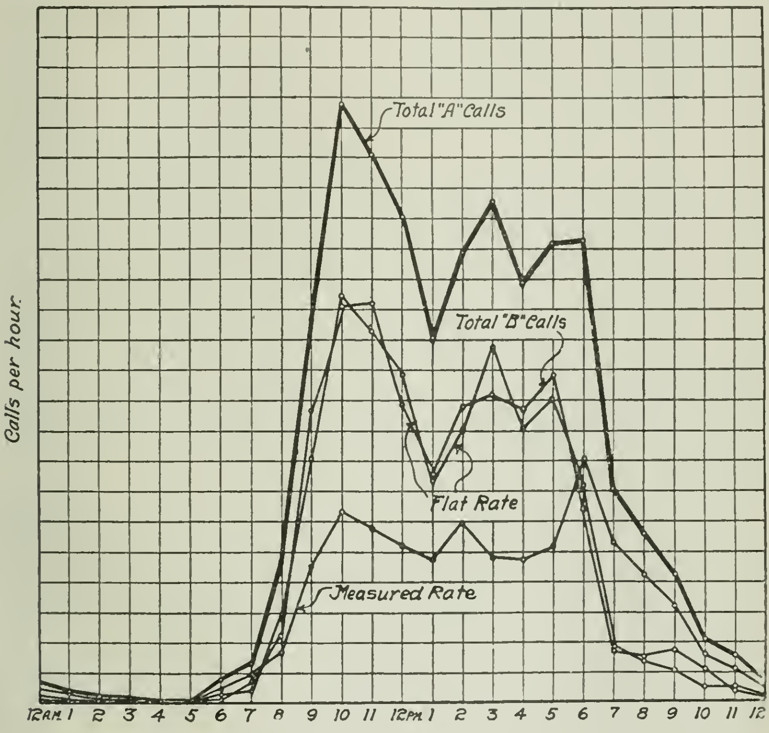

Fig. No. 15. Load curve for Monroe exchange August 3, 1906.

The great variations in the hourly use of the telephone increases in a marked degree the cost per message for operating, because the telephone company must always have sufficient operators on hand to meet the requirements of the hour, and must have a sufficiently large switchboard to enable it to handle all the calls which arrive at the busiest hour. Even with the best arranged schedule for the operators' work it is impracticable to arrange for operators to be on hand for only one or two hours in the morning and one or two hours in the afternoon, but the operators must be put at work for a considerable number of hours at a time, so that the irregularities of the load curves which run up into high peaks increase the cost of operating on account of increasing the average number of operators that must be kept on duty in proportion to the total number of calls per day, and also increase the cost for interest and maintenance on account of the extra switchboard positions required to enable these extra operators to perform their work.

A scrutiny of the load curves of the various exchange offices and especially of the business offices, indicates that the greatest proportion of the peak of the load in each exchange office comes from the flat rate users, and that the measured rate curve is more uniform over the period of the day. This absence of peak makes it possible to perform the telephone service more economically, and the present measured rate users are therefore less expensive users to whom to supply service. A measure of the expense of operating is to some degree indicated by the ratio of the maximum number of calls in the busy hour to the total number of calls per day in the exchange. This ratio is larger for the flat rate calls than for the measured rate calls in the Chicago exchange district. As shown by the twelve "peg counts" for 1906, the average ratio for the total number of originating calls is .1072, the ratio for the flat rate calls is .1185, and the ratio for all measured rate calls, including ten-party lines, is .0991, which indicates that the cost of operating for the measured rate calls is less than the cost of operating for the flat rate calls. Other peg counts show similar results.

Service inspection tests from the New York City exchanges, which are operated almost entirely on the measured service basis, show that the proportion of unavailing calls there is only about one-sixth of the total calls, and that the proportion of calls receiving busy reports is one-twelfth of the total calls. A comparison of peg counts for these two exchange systems indicates that the expense for traffic employes per station is lower in New York than in Chicago, and the conclusion therefore is that this difference must be due to the measured rate method of charging for service.

Study of the load curves indiates farther that the way in which the calls become distributed in the system makes it possible for the telephone company to arrange its operating force more economically to take care of its present measured rate service, and therefore actually enables the telephone company to make the cost of operating less per individual call of the measured rate service than it can for the flat rate service.

On the flat rate basis the telephone subscriber who makes calls over his telephone line twenty or more times per day (perhaps even fifty or one hundred or more times) pays the same price as the subscriber who uses his telephone only eight or ten times a day, and the flat rate being an average rate which enables the telephone company to come out at the end of the year with its expenses all paid and a balance to pay interest on its investment, it is obvious that the small user pays more for his telephone than his use makes necessary and the largest user pays less for his telephone than his service probably costs the operating company. This is so manifestly unfair that there can be no justification in maintaining a strictly flat rate telephone charge in large cities with the present known methods of operating. Such charges for telephone service are as unjust as similar charges would be if made for electric light or gas. It will be recognized as absurd to suggest that a gas company should charge a fixed rate per year for each gas burner in a place of business, regardless of the number of hours that the place of business is open.

From the foregoing it will be seen that in the interest of good service, economy of production and uniform justice in charging for the different classes of service, the measured service plan is much to be preferred to the flat rate method.

A very little consideration of the expense of maintaining a telephone plant leads one to the conclusion that maintenance expenses are very largely directly due to traffic, and all maintenance expenses must be considered as being directly or indirectly due to traffic and therefore distributed in proportion to the traffic. The same may be said of general expenses and fixed charges.

Depreciation and insurance on portions of the plant, which are not economically underwritten by insurance companies are items of expense in producing telephone service which are often neglected or underestimated in the consideration of the fixing of telephone rates. Much of the depreciation on a telephone plant is directly caused by the traffic. This is especially true of the depreciation of equipment —both central office and subscribers' stations; also depreciation due to the advancement of the art, as traffic often demands that present equipment and methods be replaced by more modern ones before the ones in use have been worn out. The depreciation on parts of the plant which cannot be directly traceable as a result of traffic are indirectly due to it, as the object of the plant is to provide for traffic and therefore depreciation charges should be classified in proportion to the traffic. Taken in conjunction with depreciation there should be set aside a fund to cover insurance on those portions of the plant which the fire insurance companies will not underwrite at reasonable rates. An amount proportional to the value of the plant should be put into the fund each year, and the amount must be computed from experience as to the average life of the different parts of the plant, making due allowance for the "scrap" value of discarded apparatus, judgment of the rate at which street, bridge and park improvements are likely to be made which will interfere with the company's plant, and experience of the fire hazard.

The computations of the Special Telephone Commission are shown in the following table:

Property	Life in Years	Per cent to depreciation account	Per cent salvage	Per cent to reconstr'ion & insurance
Underground conduit, main, clay in concrete	50	.89	0	1½
Underground conduit, main, fibre, etc.	20	3.72	0	1½
Underground conduit, subsidiary	20	3.72	0	2
Underground cable, main	20	3.72		2
Underground cable, subsidiary	15	5.38	40	2
Aerial cable	15	5.38		3
Poles, including crossarms, etc.	10	8.73	0	4½
Aerial strand	12	7.05	0	3½
Aerial cable terminals	12	7.05	0	3
Aerial wire, copper	15	5.38	70	3
Drop wires, copper	8	11.25	15	4
Subscribers' station instruments	10	8.73	5	2
Private branch exchange switchboards	8	11.25	20	2
Central office switchboards	8	11.25	20	2
Buildings, fireproof	40	1.33	0	1
Teams, tools, furniture, etc.	4	23.92	10	0

In order to determine the proper rate to charge the cost must first be ascertained for each class of service offered, and to do this means a careful investigation and determination of all of the above questions. It means particularly that telephone companies must pay more attention to the results of their peg counts and that they must be made in such a way that they will furnish the information necessary for the accurate fixing of rates. This complex problem offers many interesting opportunities to the telephone engineer, and it is to be hoped that the great telephone companies of our large cities will soon set about a means of determining the exact cost of the different classes of telephone service, so that it may be furnished without discrimination in charges to any class of users, and so that the small user may be able to provide himself with telephone facilities at the lowest possible cost consistent with good business practice. Not until our great telephone companies can truthfully say from their own knowledge that they are doing this, can they claim to be discharging the duty which they assumed upon entering the telephone business.

DISCUSSION.

Mr. Walter H. Burgess: I have listened with much pleasure to this very able paper. I agree with the author in most of what he says, but there are one or two points that I think he did not sufficiently emphasize and these points lie at the very root of the question. He made it very clear that telephone subscribers expected first, last, and all the time to get good telephone service; that they did not expect to pay for a telephone and look upon it the same as one would look upon a hat peg or ink-stand.

The author mentioned that the unit of cost of telephone service was the message. That is only partially true, for to my mind the logical and scientific method is the message time mile, corresponding somewhat to the unit cost of a railroad system. It is obvious that the longer the distance a message is carried, the more it costs, and you will understand that it is possible to put only one message on a trunk at one time; it must be perfectly clear to you that if one subscriber takes six minutes to deliver a message, it is much more expensive to the telephone company than for a message which requires only three minutes to deliver.

The author did not touch upon the question of the quality of the service given under the two different rate classes. In my country a famous statesman said, "You cannot make men moral by act of Parliament," and you cannot compel a telephone company to give good service by any sort of law.

Inasmuch as the total revenue of a telephone company, when its subscribers are all on flat rate, is the same whether the calls are few or many. it seems to me that the telephone company has no incentive to boost up its service to increase the number of calls. As a matter of fact, it is to its interest to keep down the number of calls to the lowest possible amount. With the measured rate the revenue depends on the number of messages, therefore it is obvious that it is to the company's interest to do all in its power to keep the service up to its highest efficiency, so that the revenue will be maintained or increased.

I think some people have imagined that with a measured service they would be brought face to face with utter financial disaster, and that their telephone would be something similar to a box of cigars that an Englishman uses—only to be used occasionally.

The author called attention to the great increase in telephone subscribers in New York since 1898. and I think this is due to the fact that measured rate service was introduced about this time. In London, four years ago, the measured rate service was introduced, and I recall that the president of the National Telephone Company, in speaking at a directors meeting last August, stated that the decrease in the average income per station was due entirely to the adoption of the measured rate. I referred to figures in this connection, and found that the average income per station under the measured rate was about $3.00 less than the average income per station under the flat rate.

Mr. K. B. Miller, M.W.S.E.: I had not expected to say anything this evening, but perhaps a few words illustrating the enormous growth in the use of the telephone within the last few years, may be of interest For instance, the New York Telephone Company now adds more telephones every three months than it did during the first seventeen years of its existence. This means that the growth in the use of telephones in New York City is annually four times greater than the total growth in the first seventeen years.

I think Mr. Burgess' suggestion of the message-time-mile unit may be, perhaps, an ideal. but it seems to me that it is wholly impracticable at the present time, and—so far as I can see—in the future.

If we analyze the cost of giving telephone service from the best data we have at hand, we shall find that the cost becomes greater as the traffic increases. It has been found feasible to make a charge depending wholly or in part upon the amount of traffic. The cost also increases to some extent with the distance. and were we to follow this idea out with a view of absolute equity in charging, we would have to charge a subscriber who was located only one hundred yards away less than one who was located a quarter of a mile from the central office, in other words, we would have to grade each subscriber's line down to feet and inches, if we wanted to reach a really ideal and perfectly just way of charging for the use of his line. So also, in order to obtain absolute equity, it would be necessary not only to record the number of conversations but also the length of each, and thus we would have the three factors necessary to place the charge on the "message-time-mile" basis.

The ideal way of charging for telephone service it seems to me, at least in manually operated exchanges, would be to charge a fixed sum per month, representing those portions of the investment which are practically constant and based not on individual cases but on averages for the total number of subscribers in a given district. This charge would take care of the investment cost, that is, of the cost to the company for providing at all times facilities for the user entirely independent of any use by him of the facilities. To this charge should be added a message rate based on the variable factors which are found to be functions of the traffic.

To bring Mr. Burgess' "distance factor" into use with a view to strictly equitable charge to the subscriber leads to such a maze of perplexities that I cannot see my way out of it. In fact, we are introducing enough trouble when we try to measure the number of completed messages, and I believe that at present neither the distance factor nor the time of message factor should enter into the charge except as based upon averages rather than upon individual cases. I am of course speaking now of local service in a given community, and not of interurban or interdistrict service where it is of course necessary not only to consider the message but the length of it and the distance over which it is transmitted.

Mr. C. S. S. Howlett (Chairman): I would ask Mr. Burgess if he knows of any plant or system in any part of the world where such a charging system other than is represented by the whole message, is used. Of course in the city limits no extra charge is made, and this extra charge is made only out of the city limits.

Mr. Burgess: I think Mr. Miller is attempting to split hairs over my idea. I did not intend to bring the matter down to actual inches. In London one is allowed to talk all over the telephone district, which is my idea of distance, and he is limited to three minutes. When the time is up he is "cut off" and has to register for another call, if longer time is desired.

Mr. Miller: I had no intention of indicating that Mr. Burgess seriously meant to bring the matter of distance down to feet and inches. I was simply reducing that to an absurdity for the purpose of illustrating my point, that we cannot bring about an absolutely equitable method of charging. The New York Telephone Company charges a certain rate for service within a given district in the city and more if the conversation extends out of that district. This brings in the distance element. As for the time element, that is perhaps a more feasible scheme than strict adherence to the distance factor. Many schemes have been mentioned for charging for telephone service by the minute, and devices have been produced for recording the time of conversation, and they are not very complicated, although I would not like to see them introduced in any exchange in which I am interested.

Mr. Howlett: I noticed that in connection with the downtown telephones the peak is at 10 o'clock in the morning, while in most of the residence districts the peak is around 8 o'clock in the evening. It has occurred to me that possibly the ideas of some of the power companies, of giving a concession of some sort to those who would make use of the power at periods of the day when there is the least call for it, could be utilized in connection with telephone service.

Mr. Crumb: I think that the complications that face us in getting on to the measured rate basis are quite enough for the present. We must first educate the people and the telephone companies to the measured rate basis of charging, that being the first step; then, at some future time, we may be able to go into the matter of length of time over which the message is transmitted, the time occupied in sending the message, etc.

I might state that there is being devised at present a method of operation which in some degree takes care of the point you have brought up, and that is a method of operation whereby the load coming into the office is distributed to the operating force, so that the operating force is kept working at its highest efficiency during all of the time. Or, to illustrate the matter a little more clearly, a switchboard is made up of a number of operators' positions, and at the busy time on that switchboard all of the operators' positions are working. and sometimes they are worked to their limit. With a system of distributing the operating load now being worked out by telephone engineers, it is the object of that system to keep the operating force reduced to its minimum and working at its highest efficiency at all times, by placing the calls that come in on to the first idle operator, so that only one or two of the operators will not be working up to their fullest capacity. In the systems now in use there are often a number of operators, who are not very busy because the work is not distributed throughout the board. With the new system, the requirements will be kept down to the peak load, making the distribution more uniform, but this system has not yet been put into operation.

Mr. D. A. Fricke: Do you think it a profitable investment to install the flat rate service at $125.00 per year? I believe Mr. Crumb states in his paper that about 40 per cent of the proceeds is represented by the flat rate, and about 60 per cent by the measured rate. From this it would seem that the service at $125.00 per year is allowing very good revenue. It seems to me it would be no more than fair to cut down the nickel charge.

Mr. Crumb: It is my opinion, based upon such information as has been presented to me, that the system of charging which is now in vogue by the Chicago Telephone Company is unfair to a large number of telephone users in this city—a number are paying more than they ought to and a number are not paying as much as they should.

Prof. E. H. Freeman: Considering equity and practicability, it seems to me that the method, which has been suggested, of a certain fixed charge and a certain message charge over and above that, is the best. I would ask if Mr. Crumb can give us any idea of what percentage of the total outlay of the company might be considered a purely fixed charge? For example, in power and lighting work it varies all the way from 50 to 90 per cent. Is it within those limits in telephone work?

Mr. Crumb: I have no clear idea of what would be an equitable fixed charge. That is all regulated by the particular plant to which it is applied, and the particular conditions at that time. The fixed charge will vary in a certain city as the plant increases. For instance, if you start out with, say, eight central offices, your fixed charge may be determined as a certain amount. When the plant has increased to sixteen offices the fixed charge should be another amount—either larger or smaller, as the average length of line may increase or decrease. It depends upon certain contingencies, such as investment in real estate, etc.

Mr. Warder: As the number of exchanges is increased, more money has to be put into trunk wires, but the number of wires does not increase as rapidly as the number of subscribers, I suppose.

Mr. Crumb: That rate is constantly increasing as the number of offices is increased.

In a single office in a small town, starting out with 1,000 subscriber lines, a certain amount of the plant would be unproductive. The fixed price which would be made as the initial charge would be so much money of that idle part of the plant which is unproductive. As the plant grows you have used up more of that idle space, and you are dividing that unproductive plant among a larger number of customers; so your fixed charge in a particular case must be given careful consideration all along the line.

Prof. E. H. Freeman: In asking about the fixed charges I had in mind the conditions here in the city. In looking over the report of the Telephone Commission I noticed that in their estimate, this item amounted to about 75 per cent of the total charge, not including interest, and I was wondering whether the fixed charge would be in the neighborhood of 75 per cent. If so, it would give the man who wants the measured rate 75 per cent of the argument.

Mr. Crumb: The maintenance charge would depend very largely on the traffic, so that the fixed charges, as I have usually understood them, have been those charges for interest, taxes, insurance, etc., not including any maintenance or operating expenses. With the data that we have at hand I do not think we could arrive at any particular sum which should be set aside as an equitable amount to be charged as that initial cost. The matter should be studied and some definite figures should be arrived at.

EXPERIMENTAL DETERMINATION OF STRESSES IN WEB PLATES AND STIFFENERS OF PLATE GIRDERS.

PROF. F. E. TURNEAURE, M.W.S.E..

Presented October 16, 1907.

The design of plate girder stiffeners is one of the few features of structural design which does not lend itself reasonable well to theoretical treatment. While most of the rules of practice are based on certain rough methods of theoretical analysis the theories employed neglect such important factors that the results are unsatisfactory and vary greatly among themselves. The problem is one that, in the nature of the case, must be solved largely by experiment. It is the purpose of this paper to contribute something towards its solution by presenting results of certain experiments on plate girder webs and stiffeners, together with such theoretical discussion as may assist in interpreting the results.

The experiments consisted in numerous measurements of the distortion of the stiffeners of a plate girder under actual railroad traffic, and measurements of web-plate distortion of a special experimental girder tested in the laboratory. The work was done under the author's direction as thesis work and as special laboratory investigation at the University of Wisconsin. The latter work was carried out in detail by Mr. W. S. Kinne, Instructor in the University, who has also assisted very greatly in the preparation of the results for publication.

Theoretical Stresses in Web Plates. As an aid in judging of the significance of the experimental results a brief statement will first be given of the usual theory of web stresses for a plate girder without stiffeners. It will be assumed that the web plate remains perfectly straight and that the flange and web are rigidly united so as to act as a solid section.

(a). The shearing stress per square inch at any point in the girder is of the same amount on vertical and horizontal planes and is given by the equation

$$S = \frac{V}{I\,b} \Sigma_{c'}^{c} \, ay \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In this equation V = total vertical shear, I is the moment of inertia of the section, b = width of beam at given point and $\Sigma_{c'}^{c} \, ay$ is the statical moment of the area of the cross-section outside of the given point taken about the neutral axis. The variation of such shearing stress for a girder of usual proportions is represented in Fig. 1. The usual assumption that the shearing stress is uniform throughout the web is seen to be nearly correct.

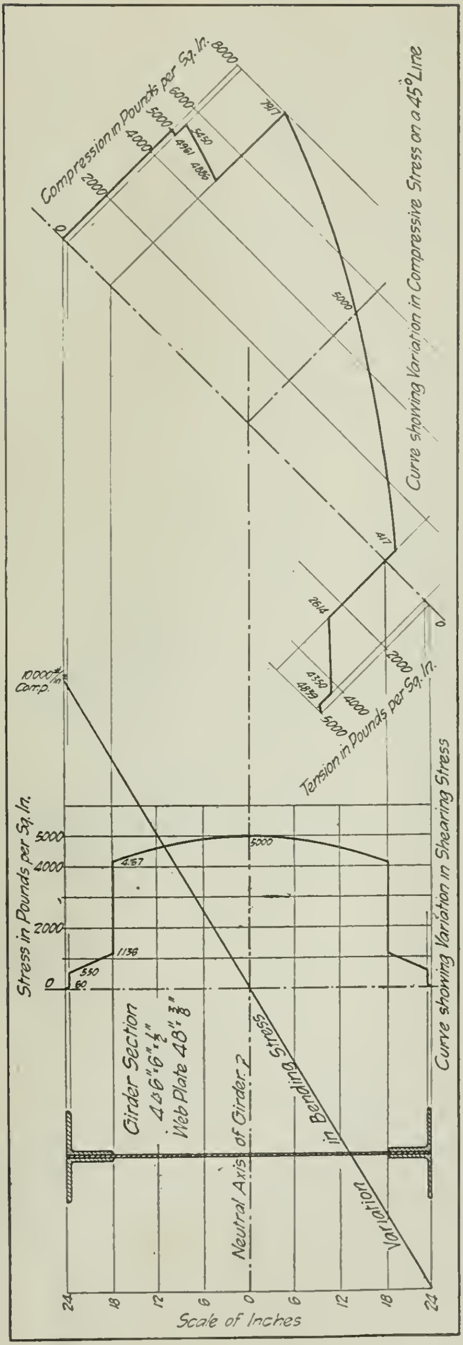
Stress in Pounds per Sq. In.
5000
4000
2000
0
60
550
1136
4167
5000
10000#/in Comp.
Girder Section
4∠6"6"½"
Web Plate 48"×⅜"
Neutral Axis of Girder
Variation in Bending Stress
Curve showing Variation in Shearing Stress
24
18
12
6
0
6
12
18
24
Scale of Inches
Compression in Pounds per Sq. In.
0
2000
4000
5000
6000
8000
5450
4961
4000
7817
5000
417
2614
4350
4839
Curve showing Variation in Compressive Stress on a 45° Line
Tension in Pounds per Sq. In.
0
2000
4000
5000

Fig. 1.
Variation in Direct and Shearing Stress in a Plate Girder.

Fig. 2.
Variation in Compression on a **45 Deg.** Line Plate Girder.

(b). The tensile and compressive stresses on vertical planes (stresses constituting the resisting moment) vary directly with the distance from the neutral axis, being zero at such axis. (See also Fig. 1).

(c). Tensile and compressive stresses on planes inclined at other angles are given by the equation

$$t = \tfrac{1}{2} p\,(1 - \cos 2\phi) + v \sin 2\phi \quad * \ldots\ldots\ \ldots\ldots\ldots (2)$$

in which p is the horizontal unit tensile or compressive stress, v the unit shearing stress at the given points as found by eq. (1), and ϕ is the angle which the given plane makes with the horizontal. At the neutral axis the tensile and compressive stress is a maximum on a plane inclined 45 deg. from the horizontal and is equal to the shearing stress. At other points the maximum intensity is at some angle greater or less than 45 deg. + v. Figs. 1 and 2 represent the variation in compressive stress along a 45 deg. line, assuming the shearing intensity at the neutral axis to be one-half the maximum tensile or compressive stress at the extreme fibre.

It is thus seen that in the web plate the tensile and compressive stresses on a 45 deg. line vary from a maximum value at one flange to a value nearly zero at the other. The average value is numerically equal to the average value of the shearing stress.

(d). The tensile and compressive stresses on horizontal planes (that is, on vertical lines) are zero at all points.

In applying the theory in practice, to determine the strength of a girder, the chief difficulty arises from the effect of the compressive stresses in the web as above noted. It is generally supposed that when a web plate fails it will fail by buckling due to these compressive stresses, but the fact that the plate is never perfectly plane at the outset, and the uncertain effect of the tensile stresses in preventing buckling make it impossible to deduce theoretically a value for strength of web plate that will be at all satisfactory. General laws can probably be thus deduced, but absolute values of the coefficients can only be determined by experiment.

EXPERIMENTS ON A THROUGH PLATE GIRDER.

The experiments here described were carried out during the past year by Mr. O. K. Peck, a senior in the Civil Engineering class in the University of Wisconsin, on a through plate girder of 75-ft. span length on the C., & N.-W. R'y. A sketch of this structure is shown in Fig. 3. The bridge is a double track structure. The web is the usual ⅜-in. plate.

The experiments consisted in the measurement, by autographic extensometers, of the stresses in the several stiffeners during the passage of trains. The extensometers were the Fraenkel type, and were the same instruments as described in a paper by the writer in the Trans. Am. Soc. C. E. Vol. XLI. The deformation is measured

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* Merriman's Mechanics of Materials, 9th Ed., p. 151.

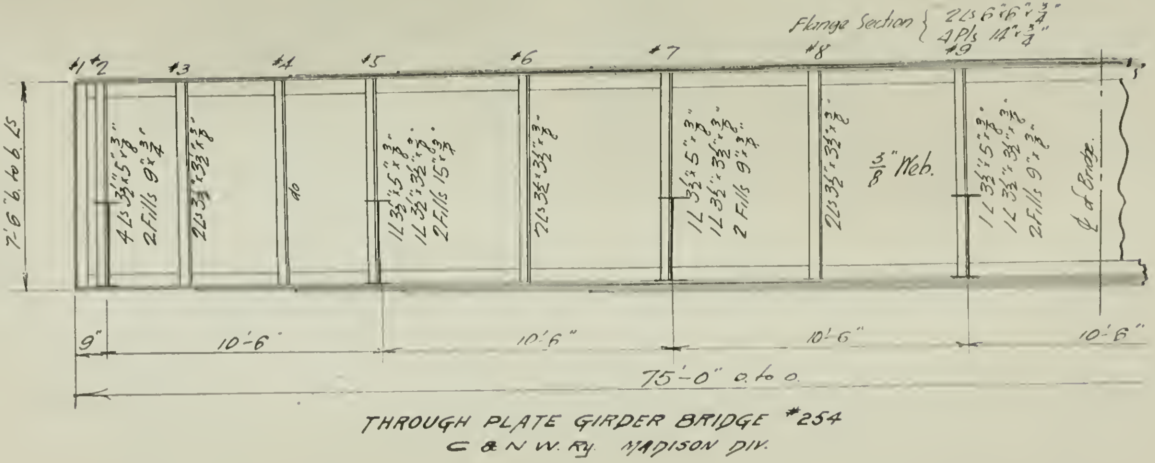

Flange Section { 2 Ls 6"x6"x¾"
4 Pls 14"x¾"
#1
#2
#3
#4
#5
#6
#7
#8
#9
4 Ls 3½"x5"x⅜"
2 Fills 9"x¾"
2 Ls 3½"x3½"x⅜"
do
1 L 3½"x5"x⅜"
1 L 3½"x3½"x⅜"
2 Fills 15"x¾"
2 Ls 3½"x3½"x⅜"
1 L 3½"x5"x⅜"
1 L 3½"x3½"x⅜"
2 Fills 9"x¾"
2 Ls 3½"x3½"x⅜"
⅝" Web.
1 L 3½"x5"x⅜"
1 L 3½"x3½"x⅜"
2 Fills 9"x⅜"
℄ of Bridge.
7'6" b. to b. Ls
9"
10'-6"
10'-6"
10'-6"
10'-6"
75'-0" c. to c.
THROUGH PLATE GIRDER BRIDGE #254
C & N W. Ry. MADISON DIV.

Fig. 3.

over a length of one meter and multiplied by a lever system having a ratio of about 1:140. The movement is recorded on a moving strip of paper. Two extensometers were used and readings were taken, where possible, on both the inside and the outside stiffener angles for one half of each girder. About 300 observations were taken. At points of connection of floor beams measurements could be taken only on the outside stiffeners on account of the gusset plates on the inside.

As the work was done under the regular traffic the results were of great variety, there being many different classes of locomotives in service on the division. Measurements were recorded only for the trains on the track nearest the girder in question. The data are arranged so that the direction of movement of train is in all cases from stiffener No. 1 towards the right, as shown in Fig. 3. Thus the maximum shears are always at the right end of the girder, at stiffeners numbered from 10 to 18. A large majority of the locomotives were of one of the three classes known as R, R-1 and D. Diagrams of these classes are given in Fig. 4. Class D was used on passenger trains and classes R and R-1 on freight. The weights of classes R and R-1 are so nearly equal that for our purposes it will be unnecessary to distinguish between them. No difference in results could be noted. These were the heaviest locomotives used. Results from other locomotives varied considerably from these, but were generally smaller. They are widely scattered and not readily comparable so they will not be given here.

Complete data are given in Table No. 1 for five stiffeners, these results being typical. In all cases the maximum ordinate of the deformation curve is given in inches and then the calculated stress per sq. in. corresponding to this value, assuming a modulus of elasticity of 30,000,000 lbs. per sq. in. The minus sign indicates tension.

Table No. 1. Typical Results Obtained on Stiffeners.

Stiffener No. 1.

Position of Angle.	Class of Engine.	Max. Ordinate. Inches.	Stress per sq. in. Pounds.
Inside	Freight	.08	440
		.08	440
	Passenger	.04	220
		.06	330
		.08	440
Outside	Freight	.17	930
		.18	980
		.10	550
	Passenger	.12	650
	Stiffener No. 2.		
Outside	Freight	.24	1360
		.24	1360
	Passenger	.22	1200

Position of Angle.	Class of Engine.	Max. Ordinate Inches.	Stress per sq. in. Pounds.
	Stiffener No. 4.		
Inside	Freight	— 28	—1530
		—.30	—1630
	Passenger	—.24	—1300
Outside	Freight	.20	1090
		.22	1200
		.24	1300
		.26	1400
		.28	1550
	Passenger	.16	872
	Stiffener No. 5.		
Outside	Freight	— 22	—1200
		—.22	—1200
		—.14	—820
	Passenger	—.18	—980
		— 24	—1300
	Stiffener No. 8.		
Inside	Freight	.06	330
		.03	160
		.01	50
	Passenger	—.08	—440
		—.10	—540
		—.10	—540
		—.10	—540
Outside	Freight	.01	110
		—.04	—270
		.03	160
		—.06	—330
		.01	110
		—.04	—270

There is usually a fair agreement among the several results on the same stiffeners, but on No. 8, and in the case of some others, the results are erratic. With such low values this is not surprising. The speed of all freight trains was slow and for the passenger trains generally from 30 to 45 miles per hour.

It will be noted that stiffener No. 4 showed tension on the inside and compression on the outside, indicating a bending or buckling tendency. This was observed in others.

In Table No. 2 are given, in a condensed form, the results on all the stiffeners. Average values are given for the stresses, obtained as above described, for the three classes of engines considered.

Table No. 2.—Average Results for all Stiffeners.

No. of Stiffener	Class of Engine	Position of Angle	No. of Observations	Aver. Max. Stress Lbs. per sq in.	Aver. of Inside & Outside Angles, Axial Stress
1	Freight	Inside	2	440	630
		Outside	3	820	
	Passenger	Inside	3	330	490
		Outside	1	650	
2	Freight	Outside	2	1360	1360
	Passenger	Outside	1	1200	1200
3	Freight	Inside	3	1040	—515
		Outside	2	—2070	
	Passenger	Inside	1	1090	—980
		Outside	1	—3050	
4	Freight	Inside	2	—1580	—140
		Outside	5	1300	
	Passenger	Inside	1	—1300	—215
		Outside	1	870	
5	Freight	Outside	3	—1090	—1090
	Passenger	Outside	2	—1140	—1140
6	Freight	Inside	4	540	50
		Outside	2	440	
	Passenger	Inside	——	——	——
		Outside	1	—980	——
7	Freight	Outside	3	—940	—940
	Passenger	Outside	1	—1630	—1630
8	Freight	Inside	3	160	55
		Outside	6	—50	
	Passenger	Inside	4	—540	—540
		Outside	1	—540	
9	Freight	Outside	2	—1040	—1040
10	Freight	Outside	1	—870	— 870
11	Freight	Inside	7	220	30
		Outside	5	—160	
	Passenger	Inside	1	650	190
		Outside	2	—270	
12	Freight	Outside	4	—980	—980
	Passenger	Outside	1	—1200	—1200
13	Freight	Inside	3	—160	—245
		Outside	4	—330	
	Passenger	Inside	1	—650	—760
		Outside	2	—870	
14	Freight	Outside	2	—980	—980
	Passenger	Outside	2	—870	—870
15	Freight	Inside	2	620	—505
		Outside	4	—1630	
	Passenger	Inside	1	540	—650
		Outside	1	—1850	
16	Freight	Inside	10	1030	—110
		Outside	2	—1250	
	Passenger	Inside	1	980	—625
		Outside	2	—2230	
17	Freight	Outside	3	1470	1470
18	Freight	Inside	1	—540	930
		Outside	1	2400	
	Passenger	Inside	2	—760	760
		Outside	1	2280	

Examining the results in detail it will be noted that in the end stiffeners, Nos. 1, 2, 17 and 18, there is considerable axial compression, as would be expected, owing to the local concentrations. These stresses are heavier in Nos. 2 and 17 than in the stiffeners at the extreme end. This also is to be expected. Stiffeners Nos. 3, 4, 15 and 16 are again alike in that they all show considerable bending, with tensile stresses on one side and compressive stresses on the

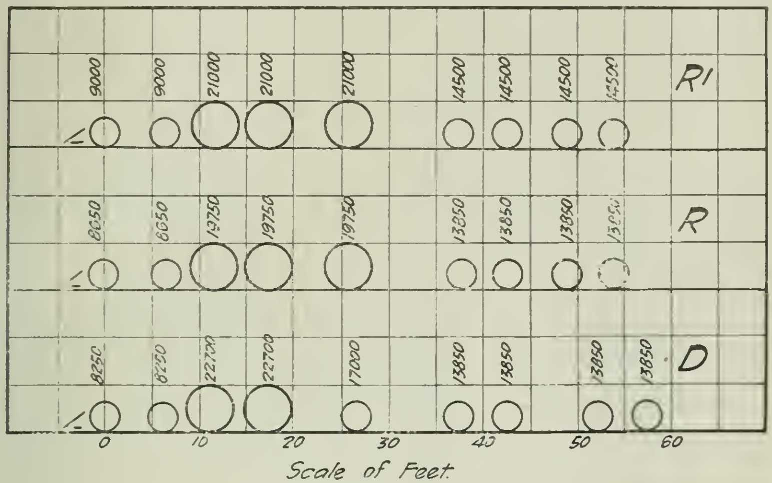


Fig. 4
Engine Diagrams.

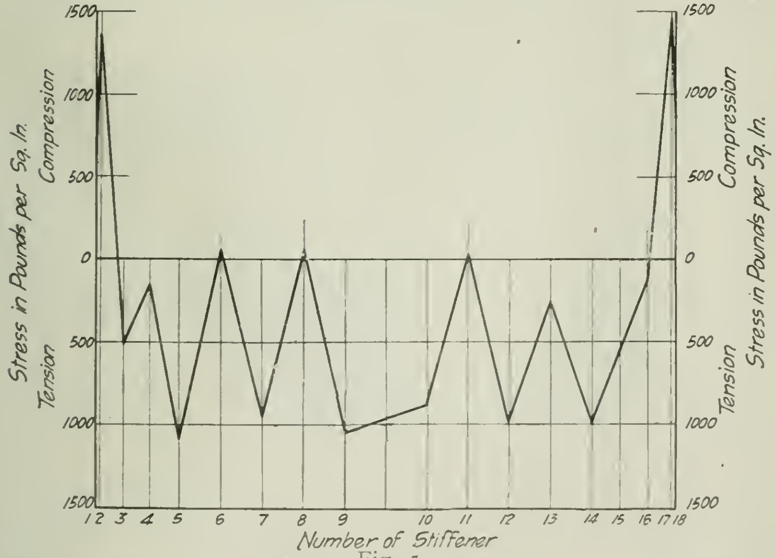


Fig. 5.
Average Axial Stress in Stiffness Under Freight Engine (from Table No. 2)

other. The axial stresses are small, being mainly tension. Nos. 6, 8, 11 and 13 show considerably less bending and small resultant stresses. It is to be further noted that the axial stresses in all these stiffeners are about the same at one end as at the other, indicating that the direction of movement has little effect.

The intermediate stiffeners to which floor-beams are attached, Nos. 5, 7, 9, 10, 12 and 14, all show tensile stresses on the outside angle. Probably the axial stress is also tensile as the gusset plate would prevent much bending. Fig. 5 is a diagram of the axial stresses from Table No. 2 for the freight engines. It represents quite clearly the general conditions.

The results of these experiments would seem to show quite conclusively:

(1), that under ordinary working conditions the axial stresses in intermediate stiffeners, subjected to no local loading, will be very small—practically nothing,—but that these stiffeners are likely to be subjected to some bending;

(2) that stiffeners at points of concentration (end stiffeners and stiffeners supporting floor-beams) will be stressed in a manner depending upon the direction and point of application of such concentration. These results are what would be expected from theoretical considerations. As shown at the beginning, the theoretical tensile or compressive stresses on vertical lines are zero. Hence it follows that stiffeners riveted on the web in a vertical position cannot receive direct stress. They aid of course in preventing bending of the web, as indicated by the bending stresses to which they are subjected. Stiffeners at points of load concentration will receive stress as the web stresses at such points involve more or less direct stress on vertical lines.

LABORATORY EXPERIMENTS ON A SPECIAL GIRDER.

To carry the work a step further a special girder was constructed in accordance with the drawing of Fig. 6. The girder was built by

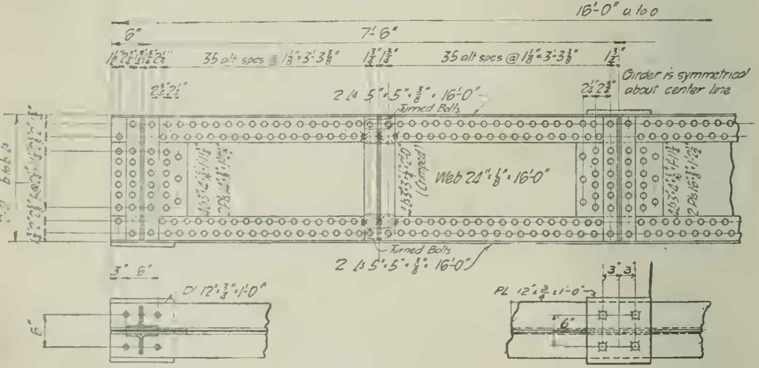


Fig. 6.
Special Experimental Girder.

the Wisconsin Bridge Company and in details it is largely the design of Mr. Andrews Allen of that Company. Test specimens of the web material showed an ultimate strength of 50,300 lb. per sq. in.—a yield point of 37,700 lb. per sq. in. and an elongation of 25 per cent; specimens of the flange material showed an ultimate strength of 60,700 lb. per sq. in. and a yield point of 45,000 lb. per sq. in.

The capacity of the testing machine available for the work was 100,000 lb. and it was the aim to secure a girder as large as could be handled in this machine and one whose web would be the weakest element. A web thickness of ⅛-inch was used with flanges very strong and thoroughly riveted to the web. It was the purpose in this experiment to study stresses in a web unsupported by stiffeners, both within and beyond the elastic limit. Stiffeners were therefore used only at points of loading and at supports. It was intended to apply loads at first at the center and then, if necessary to cause rupture, at the quarter point. Permanent stiffeners were therefore placed at the center, but at the quarter point the stiffeners were not put on till needed. They consisted of angles well bolted to the girder with machine bolts.

From the figure it will be seen that the unsupported depth of web was 14 inches. The actual thickness was 0.14-in. so that the ratio of unsupported depth to thickness was 100. The unsupported length without the stiffeners at the quarter point was 6 ft. 2 in. and with such stiffeners it was 2 ft. 7 in.

The first series of tests consisted in the application of loads at the center by increments, with measurements of web distortion by extensometers. These distortions were measured on several diagonal and vetrical lines as shown on Fig. 7. Two dial extensometers were used, one attached to each side of the web, readings being taken over a length of about 10.5 in. vertically and 15 in. diagonally.

Several runs were made with a maximum load limit of 50.000 lb. in order to obtain distoritions over the several lines shown in Fig. 7 without causing permament deformation. The results of these series are given in Table No. 3, in Fig. 7, and in the curves of Figs. 8 to 16. In Table No. 3 the stresses per square inch are calculated on the basis of 30,000,000 for the modulus of elasticity and for the center load of 50,000 lbs. Average results are given in Fig. 7, and in the diagrams, typical load-deformation curves are plotted giving the actual readings of extensometers and the average or resultant deformations. The stresses in Table No. 3 and in Fig. 7 are calculated from average deformations of the pair of extensometers and therefore represent closely the axial stress.

In Fig. 17 is given the theoretical distribution of the shearing stress over the web in this case. The theoretical tensile and compressive stresses on 45 deg. lines, as already shown, average the same. On this basis the dotted lines are drawn in the diagrams Figs. 8-16, representing the theoretical deformations. For the vertical lines (Fig. 7) the theoretical stresses are zero.

Noting some of the results in detail it will be seen that in most cases the readings of the two opposite extensometers differ greatly.

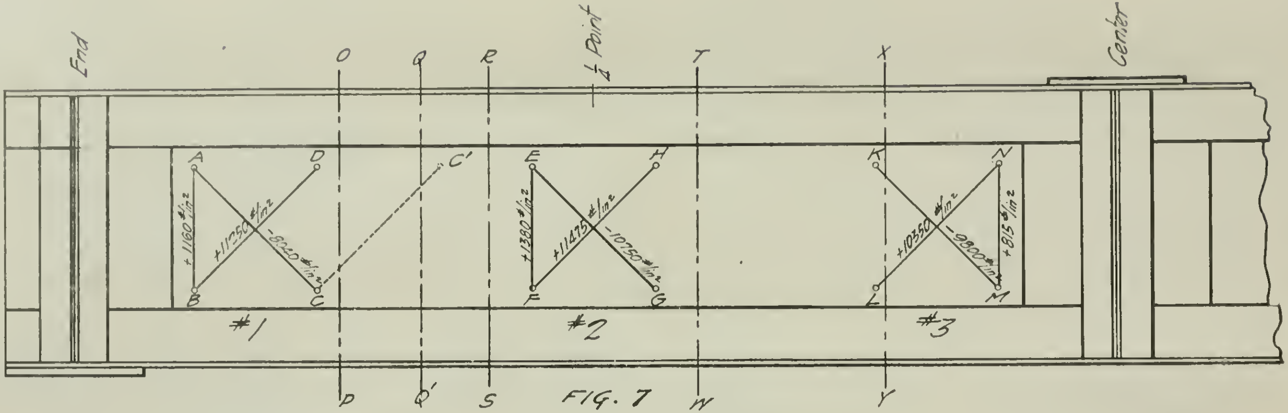


FIG. 7

DIAGRAM OF GIRDER SHOWING WEB STRESSES FOR 50000 Lbs AT CENTER OF BEAM
CALCULATED FROM WEB DISTORTIONS E = 30 000 000 #/in²

TABLE OF STRESSES (FIG. 7)

Line	AB	AC	BD	EF	EG	FH	MN	KM	LN
1st Run	1090	8200	11300	1170	10900	12150	850	9750	10350
2nd "	1230	7620	11200	1800	10600	10800	780	10050	10350
3rd "		8300		1170				9600	
Average	+ 1160	- 8040	+ 11250	+ 1380	- 10750	+ 11475	+ 815	- 9800	+ 10350

+ Denotes Compression — Denotes Tension.

Fig. 7, and Table No. 3.
Stress in Experimental Girder under Center Load of 50,000 Lbs.

In Figs. 8 and 11, for example, one shows considerable tension and the other about an equal compression. The average is nearly zero. In Figs. 9 and 15 the results are likewise of opposite sign, but the averages show considerable elongation, corresponding to the tension on the 45 deg. diagonal. This large difference in readings of the two extensometers is, of course, due to the warping or bending of the web, causing a movement of extensometers of opposite sign. This does not necessarily indicate a buckling due to over-stress but only a change in condition in the web from its initial condition. As a matter of fact the web was more or less warped initially, as all webs are. This is shown for various sections in Fig. 18. The bending of the web may thus be quite as much a "straightening" as a bending. As this tendency appears to be greater on the tension diagonals than on the compression diagonals the action would in fact appear to be more a straightening than a bending.

The actual amount of bending is not great, as the extensometers were so connected as to record the deformation at a considerable distance from the axis, about 2 inches.

There is no indication of a stress exceeding the elastic limit for

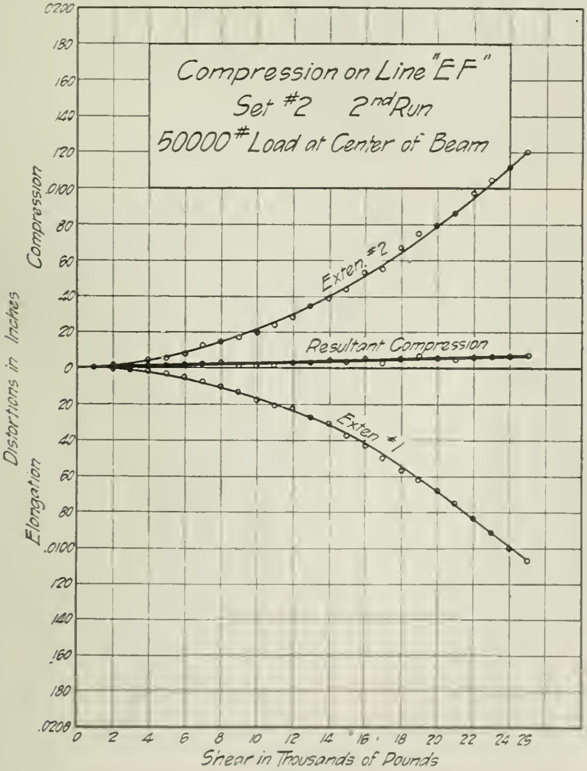


Fig. 8.

the load of 50,000 pounds. The resultant curves are practically straight lines and the different runs give practically the same results. Examining the results shown in Fig. 7 it will be noted that the aver-

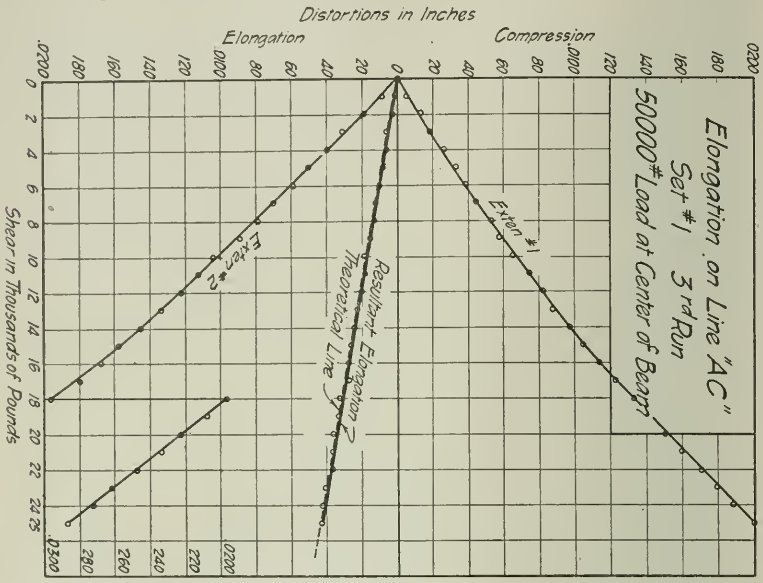


Fig. 9.

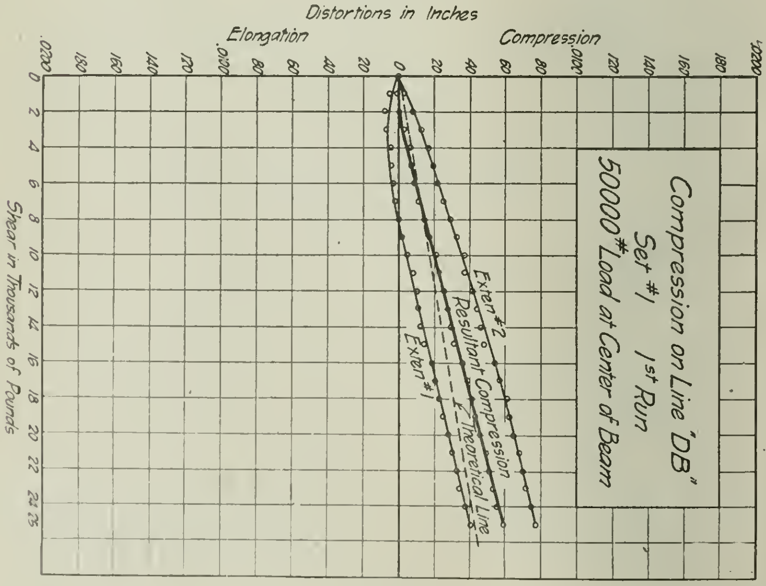


Fig. 10.

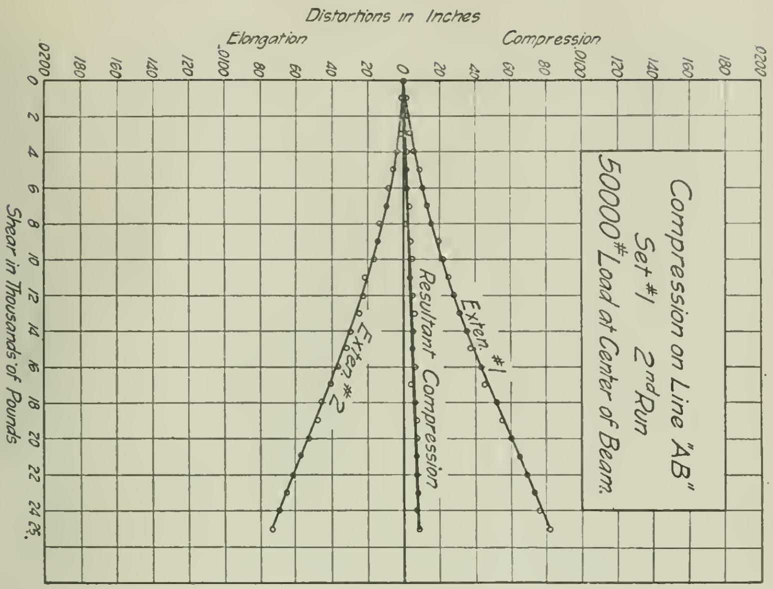

Distortions in Inches
Elongation
Compression
.0200
180
160
140
120
.0100
80
60
40
20
0
20
40
60
80
.0100
120
140
160
180
.0200
0
2
4
6
8
10
12
14
16
18
20
22
24
25
Shear in Thousands of Pounds
Exten. #2
Resultant Compression
Exten. #1
Compression on Line "AB"
Set #1 2nd Run
50000# Load at Center of Beam.

Fig. 11.

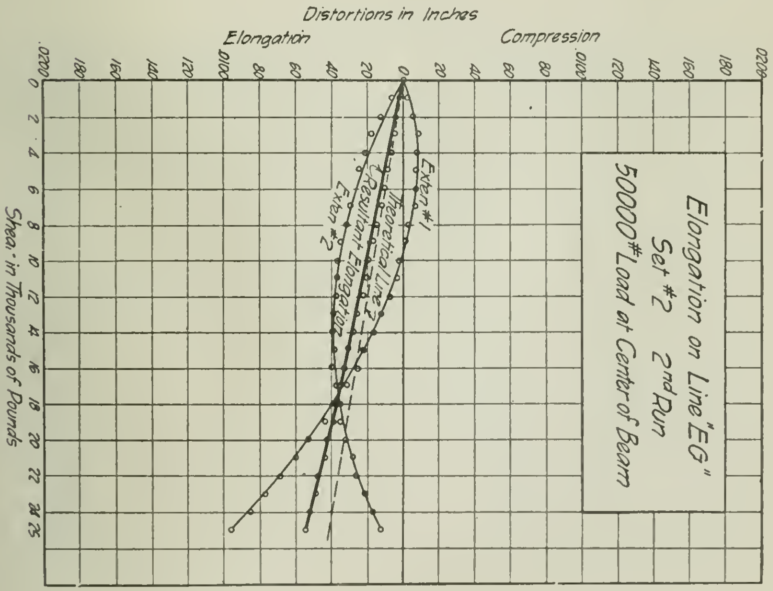

Distortions in Inches
Elongation
Compression
.0200
180
160
140
120
.0100
80
60
40
20
0
20
40
60
80
.0100
120
140
160
180
.0200
0
2
4
6
8
10
12
14
16
18
20
22
24
25
Shear in Thousands of Pounds
Exten #2
Resultant Elongation
Theoretical Line
Exten #1
Elongation on Line "EG"
Set #2 2nd Run
50000# Load at Center of Beam

Fig. 12.

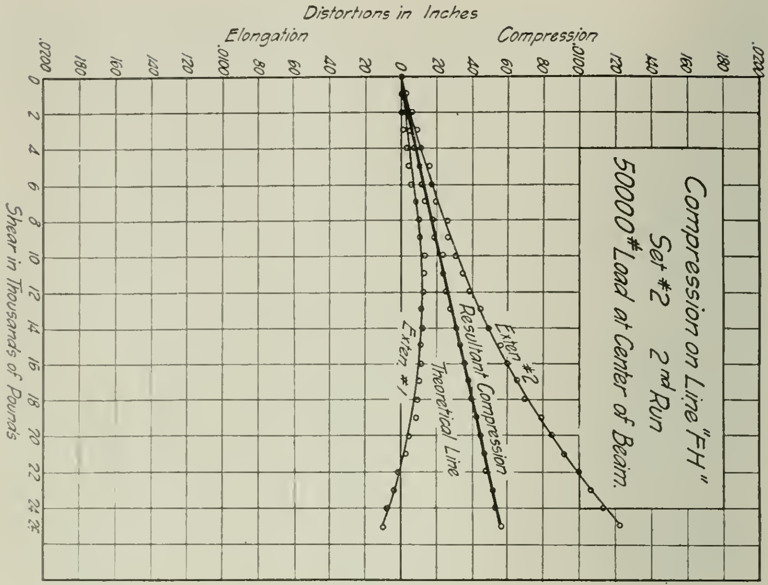

Distortions in Inches
Elongation
Compression
.0200
180
160
140
120
.0100
80
60
40
20
0
20
40
60
80
.0100
120
140
160
180
.0200
Shear in Thousands of Pounds
0
2
4
6
8
10
12
14
16
18
20
22
24
25
Compression on Line "FH"
Set #2 2nd Run
50000# Load at Center of Beam.
Exten. #2
Resultant Compression
Theoretical Line
Exten. #1

Fig. 13.

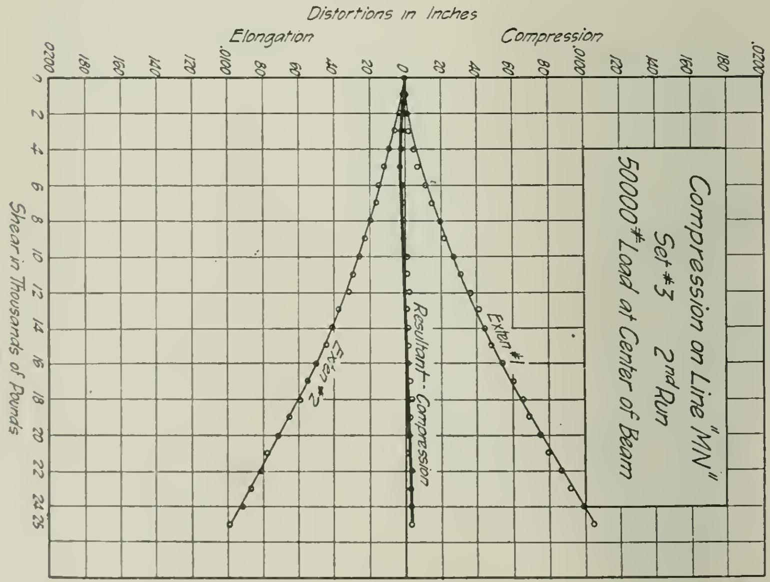

Distortions in Inches
Elongation
Compression
.0200
180
160
140
120
.0100
80
60
40
20
0
20
40
60
80
.0100
120
140
160
180
.0200
Shear in Thousands of Pounds
0
2
4
6
8
10
12
14
16
18
20
22
24
25
Compression on Line "MN"
Set #3 2nd Run
50000# Load at Center of Beam
Exten. #1
Exten. #2
Resultant Compression

Fig. 14.

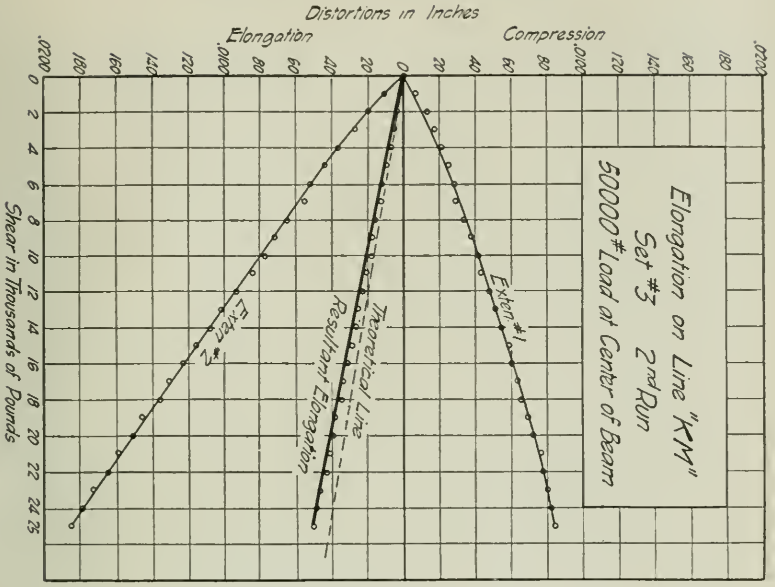

Distortions in Inches
Elongation
Compression
.0200 180 160 140 120 .0100 80 60 40 20 0 20 40 60 80 .0100 120 140 160 180 .0200
0 2 4 6 8 10 12 14 16 18 20 22 24 25
Shear in Thousands of Pounds
Exten. #2
Theoretical Line
Resultant Elongation
Exten. #1
Elongation on Line "KM"
Set #3 2nd Run
50000# Load at Center of Beam

Fig. 15.

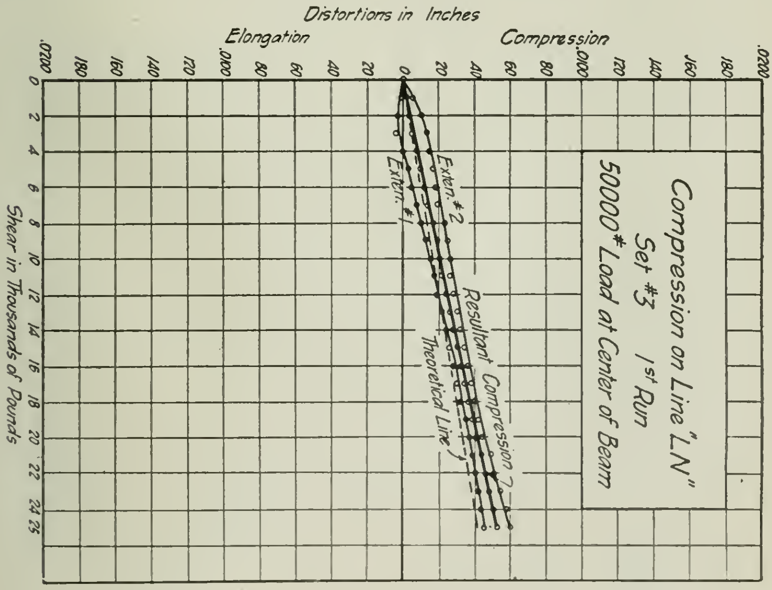

Distortions in Inches
Elongation
Compression
.0200 180 160 140 120 .0100 80 60 40 20 0 20 40 60 80 .0100 120 140 160 180 .0200
0 2 4 6 8 10 12 14 16 18 20 22 24 25
Shear in Thousands of Pounds
Exten. #1
Exten. #2
Resultant Compression
Theoretical Line
Compression on Line "LN"
Set #3 1st Run
50000# Load at Center of Beam

Fig. 16.

age diagonal compressive stress is somewhat larger than the conjugate tensile stress, the difference varying from 500 to 3200 lbs per sq. in. The vertical stresses range from 800 to 1380 lb. per sq. in. The theoretical average diagonal stress is about 8300 lb. per sq. in.

There is thus some excess of actual over theoretical stress, but considering the nature of the experiments the results may be considered as a satisfactory agreement with theory. It is to be noted further that the effect is the same at points near and remote from stiffeners. Doubtless the excess of distortion over the theoretical is due to the bending and warping action of the web.

Following the series of tests described, loads were then applied up to a maximum of 100,000 pounds at the center. Elongation line E G and compression line F H were measured. The results are shown in Figs. 19 and 20 with theoretical lines as before. Averages only of the two extensometers have been shown. In these curves there appears to be a marked elastic limit point at from 30,000 to 32,000 lbs shear. (60,000-64,000 pounds load). The compression on line F H on a second run is given in Fig. 21. This indicates generally an increased deformation. The condition of the web as to buckling is shown in Fig. 18. This indicates a large permanent deformation under 100,000 pounds center load.

The load was now shifted to the quarter point and 100,000 pounds applied. Measurements were made on line C C′ (Fig. 7). with results shown in Fig. 22 and buckling effects as shown in Figs. 23 and 24. The permanent distortion was now excessive under the shear of 75,000 pounds.

Upon the completion of a testing machine of larger capacity the test was continued to rupture with results as shown in Fig. 23 and in the photographs of Figs. 25 and 26. The girder failed primarily by buckling in a series of sharp wrinkles, but ultimately by the web tearing apart on lines about at right angles to these wrinkles. At these larger distortions the individual bending resistance of the flanges added considerably to the strength of the girder, estimated at from 10,000 to 15,000 pounds, considered as total shear. The shear at ultimate load was 104,700 pounds.

Summarizing these results we find good elastic conditions were maintained for loads of 50,000 pounds (25,000 pounds shear), that the elastic limit was reached at a shear of about 30,000 pounds and that final failure occurred at a shear of 104,700 pounds, although, considering the large permanent buckling occurring at earlier loads and the effect of the large flanges, a value of 75,000-80,000 pounds may be considered as a more significant measure of the web strength.

On the assumption of stress variation of Fig. 17 the average shearing stress in the web at these different stages would be as follows:

Total Shear, Pounds	Av. Shearing Stress in Web between Flanges, per sq. in.
25,000	8,300
30,000	9,930
80,000	26,500
104,700	34,700

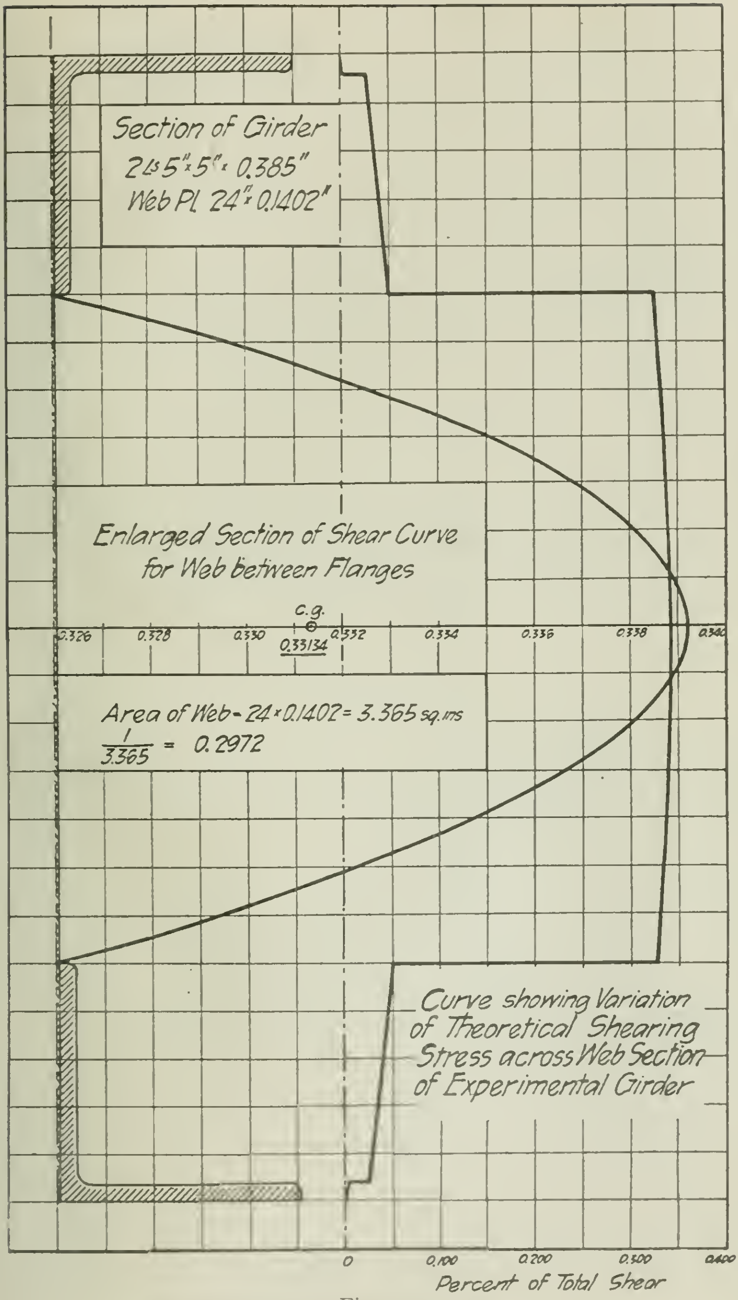

Section of Girder
2∠s 5"×5"× 0.385"
Web Pl. 24"× 0.1402"
Enlarged Section of Shear Curve
for Web between Flanges
c.g.
0.326
0.328
0.330
0.33134
0.332
0.334
0.336
0.338
0.340
Area of Web = 24×0.1402 = 3.365 sq. ins
1/3.365 = 0.2972
Curve showing Variation
of Theoretical Shearing
Stress across Web Section
of Experimental Girder
0
0.100
0.200
0.300
0.400
Percent of Total Shear

Fig. 17.

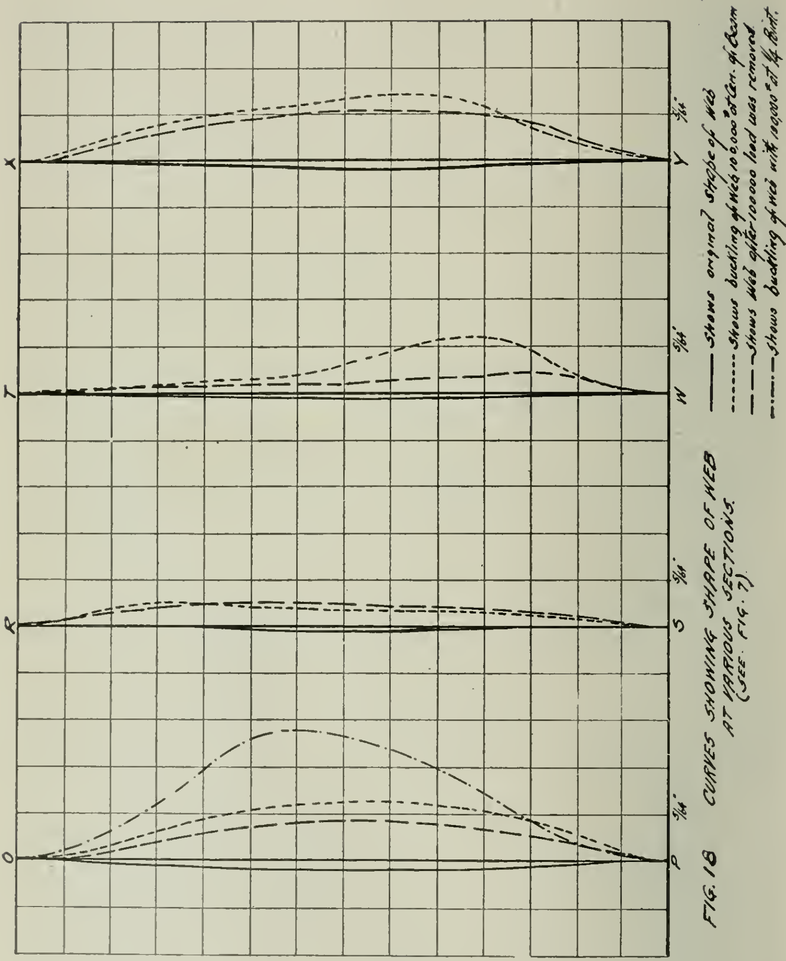


FIG. 18 CURVES SHOWING SHAPE OF WEB AT VARIOUS SECTIONS. (SEE FIG. 7).
X
Y
T
W
R
S
O
P
5/64"
5/64"
5/64"
5/64"
—— Shows original shape of web
------ Shows buckling of web 100,000# at Cen. of Beam
— — — Shows web after 100000 load was removed
—·—·— Shows buckling of web with 110,000# at 1/4 Point.

Fig. 18.

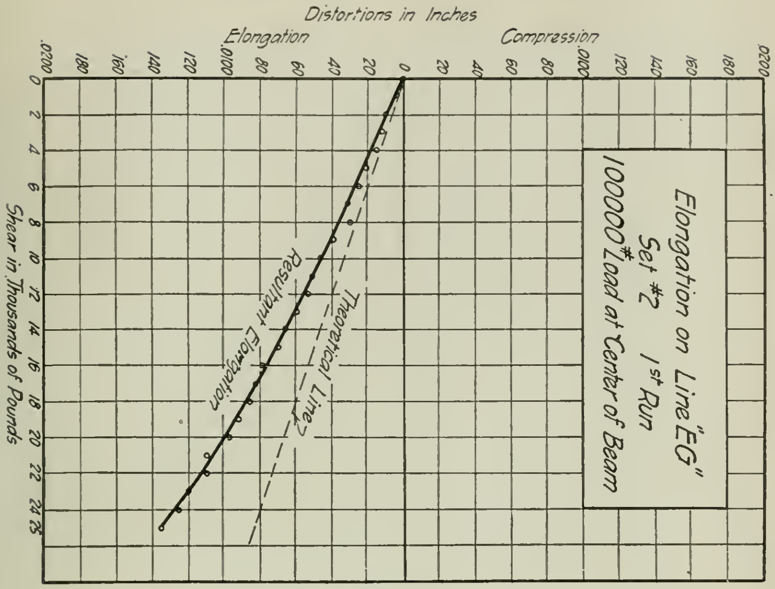

Distortions in Inches
Elongation
Compression
.0200
180
160
140
120
.0100
80
60
40
20
0
20
40
60
80
.0100
120
140
160
180
.0200
Shear in Thousands of Pounds
0
2
4
6
8
10
12
14
16
18
20
22
24
25
Elongation on Line "EG"
Set #2 1st Run
100000# Load at Center of Beam
Resultant Elongation
Theoretical Line

Fig. 19.

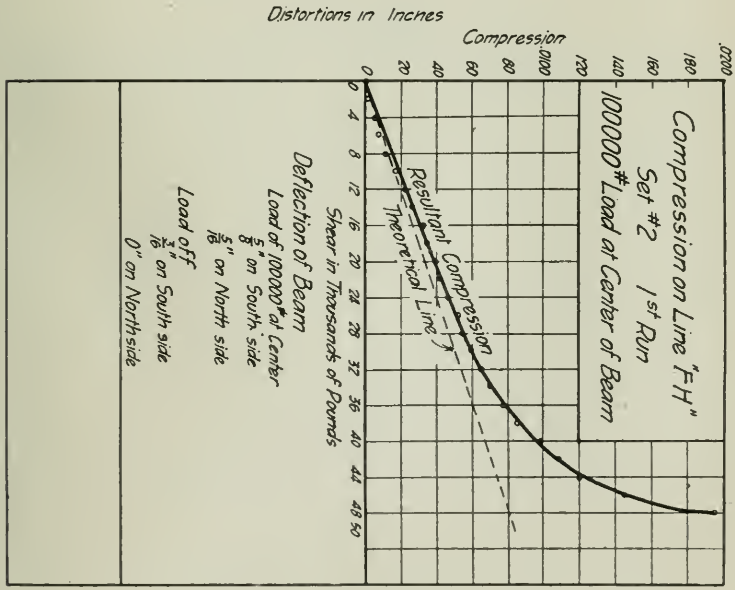

Distortions in Inches
Compression
0
20
40
60
80
.0100
120
140
160
180
.0200
Compression on Line "FH"
Set #2 1st Run
100000# Load at Center of Beam
Resultant Compression
Theoretical Line
Shear in Thousands of Pounds
0
4
8
12
16
20
24
28
32
36
40
44
48
50
Deflection of Beam
Load of 100000# at Center
5/8" on South side
5/16" on North side
Load off
3/16" on South side
0" on North side

Fig. 20.

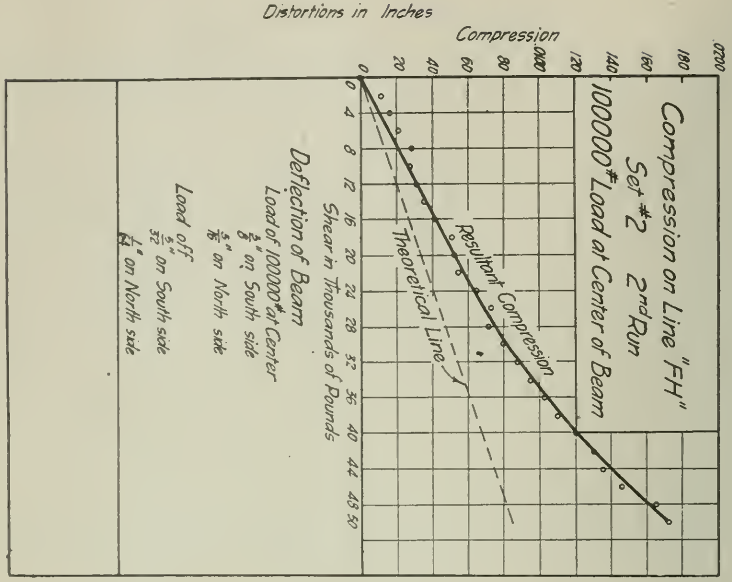

Compression on Line "FH"
Set #2 2nd Run
100000# Load at Center of Beam
Distortions in Inches
Compression
0
20
40
60
80
.0100
120
140
160
180
.0200
Shear in Thousands of Pounds
0
4
8
12
16
20
24
28
32
36
40
44
48 50
Resultant Compression
Theoretical Line
Deflection of Beam
Load of 100000# at Center
3/8" on South side
5/16" on North side
Load off
5/32" on South side
1/64" on North side

Fig. 21.

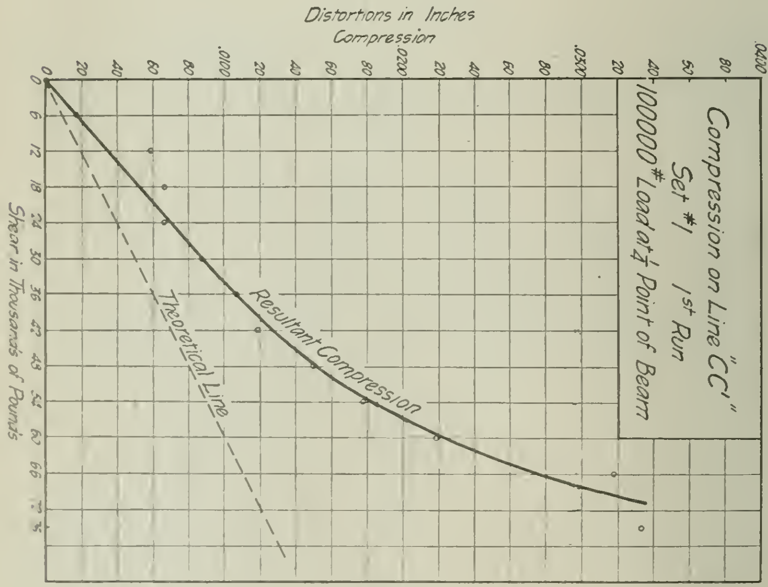

Compression on Line "CC'"
Set #1 1st Run
100000# Load at 1/4 Point of Beam
Distortions in Inches
Compression
0
20
40
60
80
.0100
20
40
60
80
.0200
20
40
60
80
.0300
20
40
60
80
.0400
Shear in Thousands of Pounds
0
6
12
18
24
30
36
42
48
54
60
66
Resultant Compression
Theoretical Line

Fig. 22.

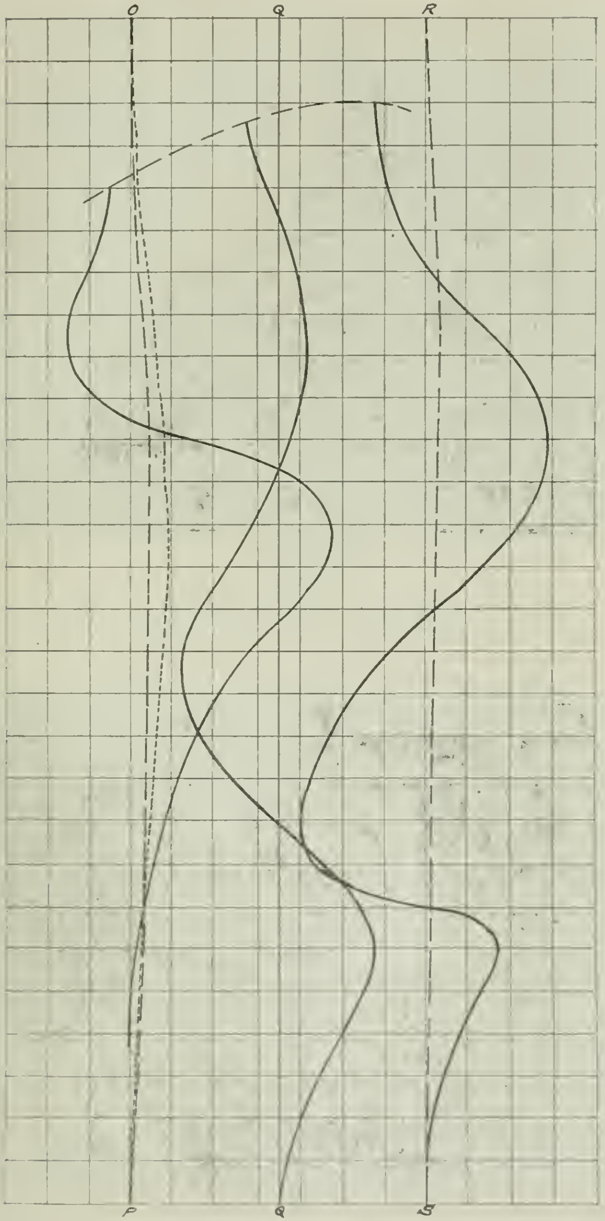


FIG. 23

CURVES SHOWING SHAPE OF WEB AFTER FAILURE OF BEAM.
SCALE FULL SIZE

——— Shows shape of web after failure 139600# at 1/4 Point.
- - - - - " " " " with 100,000# at 1/4 Point.
— - — — " " " " " 100,000# at Center

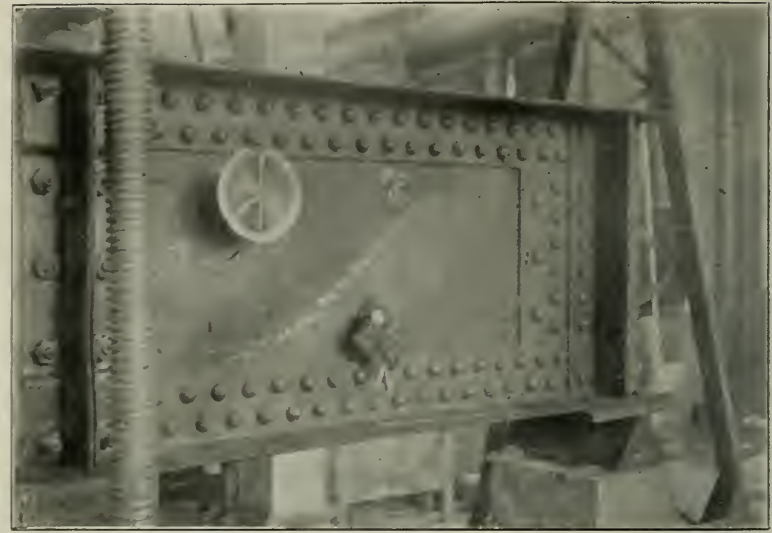


Fig. 24.

100,000 Lb. at "Quarter Point."

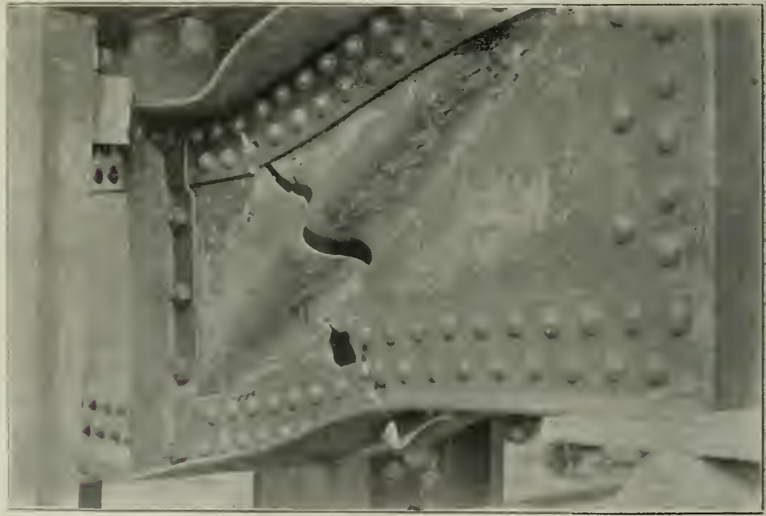


Fig. 25.

Girder after Failure.

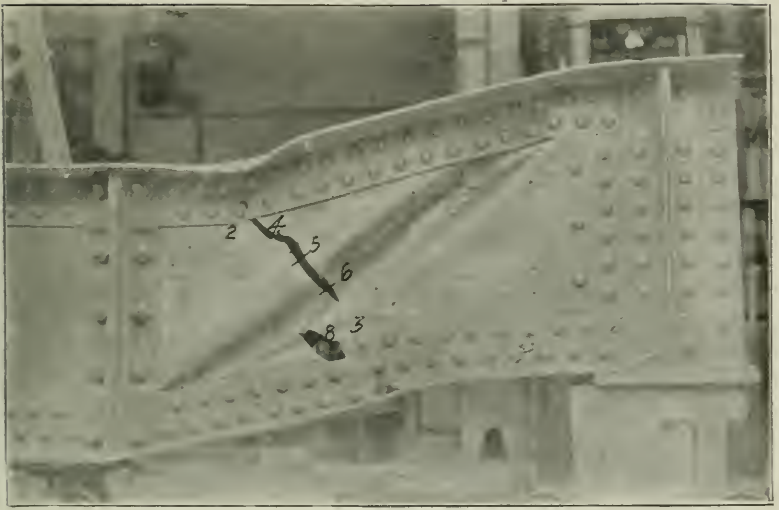


Fig. 26.

Showing Progress of Final Failure.

1. Top angles buckled at a load of 112,000 lbs. at quarter point.
2. Top angle began to tear at load of 120,000 lbs.
3. Bottom angle began to tear at load of 128,000 lbs.
4. and 5. Web opened at load of 132,000 lbs.
5, 6, 7, 8. Web opened progressively at loads of 136,000 to 139,000 lbs.
Maximum load was 139,600 lbs.

After excessive buckling occurred the stresses were greatly modified locally. The flanges began to crack and finally the web opened up at several points as shown in the photographs.

Some comparison may perhaps be made with theoretical values on the diagonal column theory. On a diagonal line the unsupported length is about 140 times the thickness. For a column with fixed ends Euler's formula gives as the ultimate load $P = 4\pi^2 \frac{E\,I}{l^2}$ In pounds per sq. in. this reduces to $p = \frac{1}{3}\pi^2 E(\frac{t}{l})^2$ in which $t =$ thickness and $l =$ unsupported length of column. Applying this to the case in hand the ultimate buckling strength is found to be 5000 lbs. per sq. in.

In the girder tested the elastic strength is about 10,000 lbs. per sq. in., and considering the nature of the case one half of the value, or 5000 lbs. per sq. in. may be taken as a safe value. This is equal to the ultimate strength by Euler's formula: It follows from this that if it may be assumed that the buckling strength of a web varies with $(\frac{t}{l})^2$, as in Euler's formula, then the safe strength for any web without stiffeners would be approximately equal to the ultimate strength as determined by Euler's formula, but not of course exceeding the limiting safe strength permitted for shear. [It seems proper to use Euler's formula here for comparative purposes in preference to other column formulas as the member considered is relatively slender].

Comparing these results with practice, a common rule is that stiffeners are not needed if the unsupported width of web is not more than 60 times its thickness. If 10,000 lbs. be taken as the limiting stress for a web plate and assuming the same law of strength to hold for shallower beams the tests would indicate that a safe strength of 10,000 lbs. would be reached by decreasing the ratio of depth to thickness from 100 to $100 \times \sqrt{\frac{1}{2}}$ or to 70. This would indicate that present practice is not far from correct. A ratio of 80 to 1 as is sometimes used, would appear to be too high. Again, some specifications would permit in such a web as here tested a stress according to the following formula,

$S = 10000\text{-}75\frac{d}{t}$ where $\frac{d}{t}$ is the ratio of the depth to thickness. This would give a value of 2500 lb. per sq. in., a value much below than here found.

As to the probable effect of stiffeners, it is to a large extent problematical. The horizontal clear space between stiffening plates, with a load at the quarter point, was 2 ft., 7 in., or 2.2 times the vertical distance. It is not likely that the spacing was close enough to materially strengthen the web. The wrinkles had already begun to develop under center load and before the stiffeners were bolted on at the quarter point. These wrinkles were practically at 45 deg. and it was these same wrinkles that developed at failure to the extent shown in the photographs. It would seem, however, from an inspection of the photographs, that a spacing of stiffeners a little closer than that used would have afforded some aid, and that a spacing equal to the vertical clear space between flanges would have aided materially. With reference to this point, it is expected that further tests will be made.

As general conclusions that may be drawn from the tests herein described, the following are offered:

1. The stresses in web plates without stiffeners, when stressed within their elastic limit, agree closely with the theoretical stresses.
2. The stresses in web plates with stiffeners, when stressed within the elastic limit, agree closely with the theoretical stresses; and as a necessary result the axial stresses in vertical stiffeners, not subjected to local loads, are practically zero.
3. The bending stresses in vertical stiffeners may be considerable.
4. The elastic limit strength of a web plate without stiffeners is, in the case here noted, about twice the ultimate strength given by Euler's column formula applied to a diagonal column element.
5. If the strength of a web plate without stiffeners may be assumed to vary as $(\frac{t}{l})^2$, then the practice of omitting stiffeners when $\frac{t}{l}$ is more than $\frac{1}{60}$ is nearly correct.

DISCUSSION.

Mr. Andrews Allen (Chairman): This paper will appeal to all designers of steel bridges, as it relates to a subject on which very little experimental work has been done. As a matter of fact, the web plates of girders seldom give evidence of weakness, even where they are carrying traffic far above the capacity for which they were designed.

Much of our knowledge of engineering structures has come to us from observation of their behavior under strains beyond their normal capacity and even more valuable knowledge, I regret to say, is frequently obtained from our failures. Very little in regard to web stresses has been learned in either of the above ways.

The stresses in webs have been determined analytically and also experimentally by means of thermal measurement and by extensometer readings, but I do not know of any experiments, except those described this evening, that have been made upon a specially constructed girder, designed to bring out the weaknesses of the web and to indicate its method of failure.

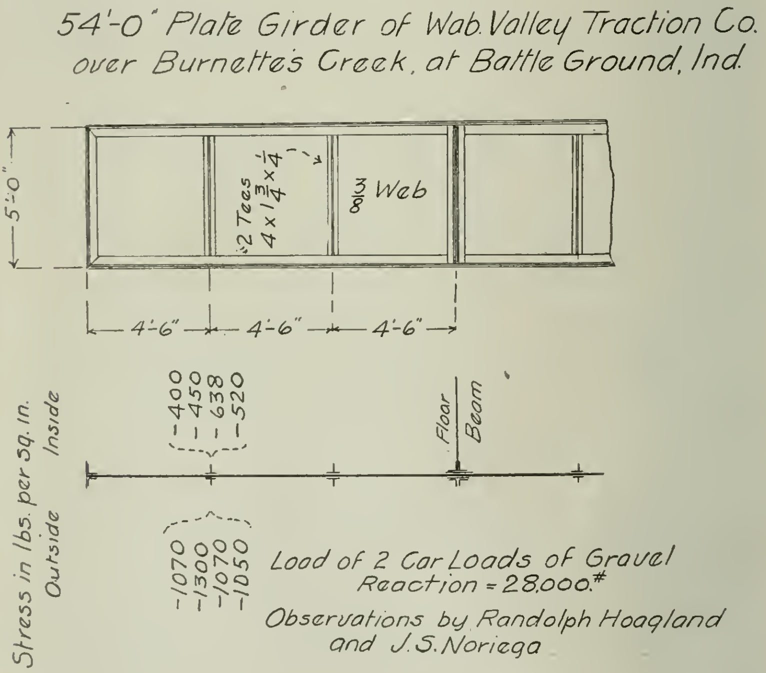
It may be said, of course, that this girder is an abnormal production, and therefore does not give us a very good indication of the way a web behaves in a properly designed girder. All this is true, but it was necessary to make the girder abnormal in order to get any results at all on the web. The web had to be made so weak relatively to the flanges that it would fail under some practicable stress and so that it would begin to show weakness before the flanges were affected.

I believe that these experiments will add something to the knowledge of the world on the question of web stresses and I think we should feel especially complimented in having them first presented before our Society. Of course, as Prof. Turneaure has indicated, these experments leave many questions undetermined, and a large field for future experiments. The structural designer, however, is especially interested in the practical deductions from these experiments, and I hope that the discussion will cover such deductions as the proper spacing of rivets, the proper spacing of stiffeners and the determination of their size, also the proper method of splicing girder web plates.

Mr. J. W. Ludlow, M.W.S.E.: In addition to the deductions here derived, I thought as I read the paper that it would have been interesting if there had been some general deductions that would throw some light on a cross-section of those stiffeners. There is given, in these tests upon a railway girder in service, the stress per square inch, and I am wondering if that was sufficient, with the few tests that could be made on each one, to aid in deriving any general conclusions regarding the sections of those stiffeners, that should be adopted in general practice.

Another point is in regard to the end angles in this railway girder. I notice by the stresses developed in these end angles that the inside two angles of the set of four receive practically 70 per cent. of the entire load, or the stresses are in that ratio. A custom which has varied widely among bridge engineers, is, how much difference should be made in inside and outside stiffener angles, or whether any difference should be made. Some take three-quarters, and that seems to be thoroughly justified by these results. Others insist that they should be made practically equal. I am wondering whether these experiments are sufficient to give any definite information, and perhaps the author of this paper can give us more light along this line.

Prof. Albert Smith, M.W.S.E.: There have been made in the past two years, under my supervision, a series of tests on plate girder stiffeners by students doing thesis work at Purdue University. In the course of these observations we have made tests on three plate girders in actual service and one model plate girder. The results on the model plate girder were rather unsatisfactory. Being dissatisfied with those results, we attached an extensometer to the outstanding legs of the stiffeners of an old railway plate girder now in use by the Wabash Valley Traction Co. The tests on two stiffeners inside and outside at a single point showed a tension, much to our surprise. The stresses found may be seen on the sketch Fig. 27.



54'-0" Plate Girder of Wab. Valley Traction Co. over Burnette's Creek, at Battle Ground, Ind.

Load of 2 Car Loads of Gravel
Reaction = 28,000.#

Observations by Randolph Hoagland and J. S. Noriega

FIG. 27.

The experiments were then discontinued for that year. Last year observations were made on two railway plate girders of the deck type, and in a series of three observations on a 44 ft. 6 in. span and three on an 80 ft. span we found compression in all but one of them.

Referring to Fig. 28 shows the dimensions of the stiffness and the results of the observation.

These tests were made with a rolling extensometer. Owing to the fact that the reading had to be taken through a telescope on the image of a level rod, it was impossible to observe high speed trains, so we had to wait for a particular train which would stop directly on the bridge. That prolonged the work considerably and made it impossible to make more tests. However, the observations on slowly moving trains with cars directly over the point of observation showed that the cars brought almost no stress in the stiffener; that the stress in the stiffener was produced by the engine.

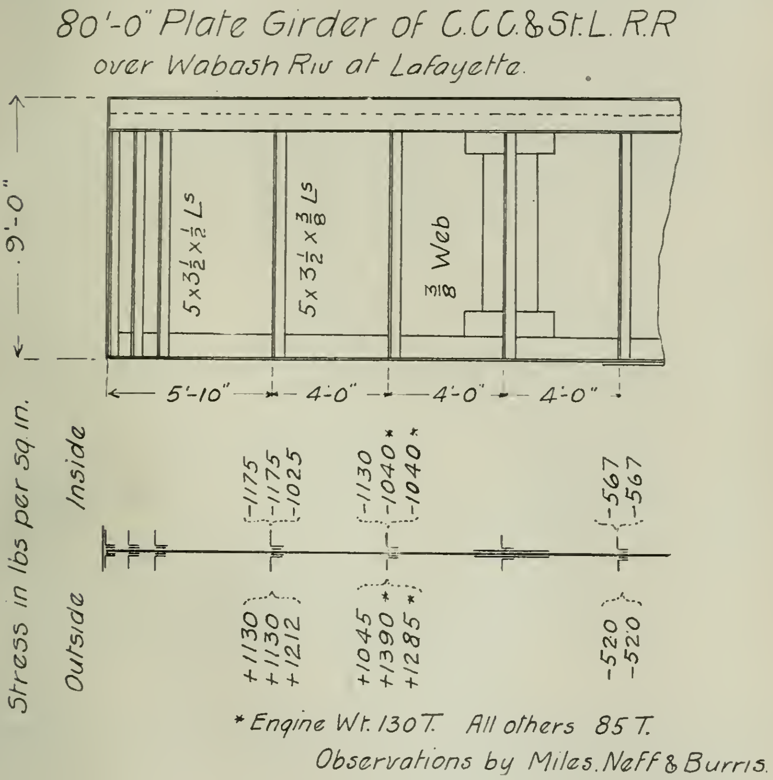

80'-0" Plate Girder of C.C.C.&St.L. R.R
over Wabash Riv at Lafayette.
9'-0"
5 x 3½ x ½ Ls
5 x 3½ x ⅜ Ls
⅜ Web
5'-10"
4'-0"
4'-0"
4'-0"
Stress in lbs per sq. in.
Inside
-1175
-1175
-1025
-1130
-1040*
-1040*
-567
-567
Outside
+1130
+1130
+1212
+1045
+1390*
+1285*
-520
-520
* Engine Wt. 130 T. All others 85 T.
Observations by Miles, Neff & Burris.

FIG. 28.

The tests on a 44 ft. 6 in. girder follow in general character, those on the 80 ft. girder; the results of these tests are shown in Fig. 29.

The most interesting point to me in those observations was the fact that a few seconds after the train passed off the bridge, we noticed a slow return of the reading of the instrument. It did not make its complete return until a few seconds after the load was removed.

In connection with tests made sometime before it would seem to me to indicate that rivets of a long joint slip.

I am inclined to think that the stress on the rivets of a plate girder is not of the same character through all of its loading; at its heaviest loading some rivets are likely to slip, and after the load is removed those rivets are not likely to pull back to their original position. We hope to have some tests later on which will aid us in this respect. In general the results we have very strongly resemble the results Prof. Turneaure has obtained.

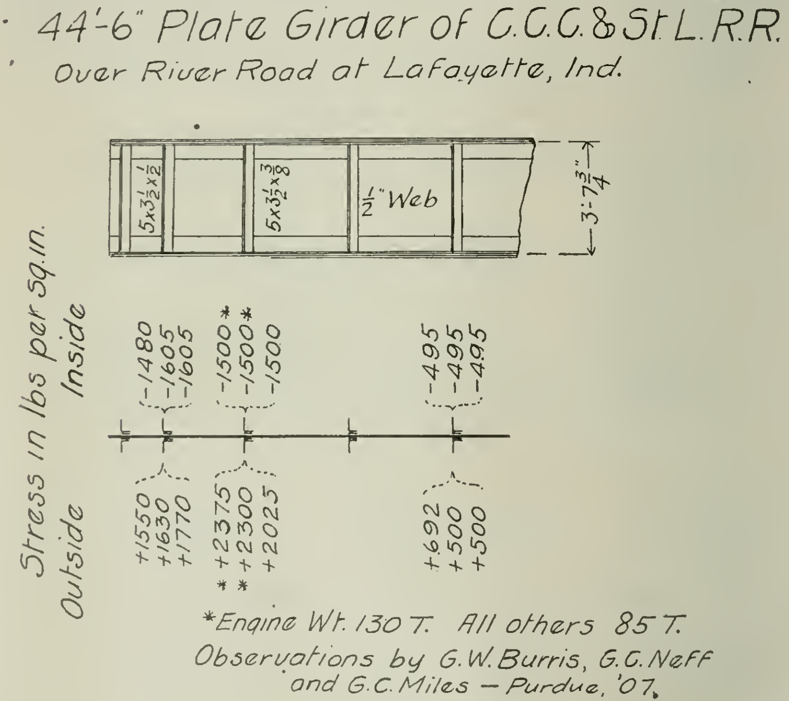

44'-6" Plate Girder of C.C.C.&St.L.R.R.
Over River Road at Lafayette, Ind.
5x3½x½
5x3½x⅜
½" Web
3'-7¾"
Stress in lbs per sq.in.
Inside
Outside
-1480
-1605
-1605
-1500*
-1500*
-1500
-495
-495
-495
+1550
+1630
+1770
+2375*
+2300*
+2025
+692
+500
+500
*Engine Wt. 130 T. All others 85 T.
Observations by G.W. Burris, G.C. Neff
and G.C. Miles — Purdue, '07.

FIG. 29.

Mr. Allen: At what point in the stiffener were these observations taken?

Prof. Smith: Just about the middle.

Mr. Allen: That would probably indicate that stresses in the stiffener are largely local.

Prof. O. H. Basquin, M.W.S.E.: I will refer to page 3, paragraph d, of the paper: "The tensile and compressive stresses on horizontal planes are zero at all points." I suppose that this statement applies only on the supposition of a uniform section from end to end; the introduction of a stiffener slightly changes the application of this statement for the reason that in the upper half of the girder there is compressive stress on vertical planes; therefore the upper half of the girder becomes a little deeper, due to the distortion at right angels, the ratio of strains in the two directions being about one-third. If a stiffener is introduced to constrain this distortion in a vertical direction, there ought to be a tension, it seems to me, in this stiffener in the upper half, and a corresponding compression in the lower half of the stiffener. This is not of any great importance, because it would never be one-third of the corresponding compression or tensile stress of the web. It may, however, account for the divergent results which Prof. Smith has recorded in his experiments.

Mr. Allen: I have here some data relating to specification requirements for stiffeners on different railroads. It will be of interest, possibly, as indicating the very wide diversion, in present practice and opinion, on this very important question. The list covers seven or eight specifications and was taken at random from our files.

(1) Cooper, 1896—Unit stress allowed in web

$$= \frac{12.000}{1 - \frac{d^2}{3000\,t^2}}$$

(1) Cooper, 1906—Unit stress allowed in web $10{,}000 - 75\frac{d}{t}$

Wabash, 1896—Thickness of 1/60 of unsupported depth, allowed without stiffeners.

(2) Wabash, 1905—Unit stress allowed in web $12{,}000 - 40\frac{d}{t}$

Frisco, 1901—Thickness of 1/80 of unsupported depth, allowed without stiffeners.

Frisco, 1906—Thickness of 1/60 of unsupported depth, allowed without stiffeners.

Missouri Pacific, 1902—Thickness of 1/60 of unsupported depth, allowed without stiffeners.

(2) Western Pacific—Unit stress allowed in web $16{,}000 - 100\frac{d}{t}$

(2) Am. Ry. Eng. & M. of W. Assc'n, Unit stress allowed in web $12{,}000 - 40\frac{d}{t}$

American Bridge Co.—Thickness of 1/60 unsupported depth, allowed without stiffeners.

(1) Unit stresses—10.000 live—20.000 dead.
(2) Unit stresses—16.000 lbs. for dead, live, and impact.

It may possibly be of some interest to suggest some considerations in regard to the splicing of webs. These considerations are hardly in the nature of deductions from these experiments, but they bear on the same subject, and are well illustrated by the experiments.

It can now be considered established practice, in girder design, to count the web plate as effective in bending. This makes it necessary to splice the web plates to resist longitudinal forces, usually by the rule of thumb equivalent to 1/6 or 1/8 of the web, and it has been customary to take care of the longitudinal forces by placing longitudinal splice plates just inside the flange angles at the top and bottom of girder, leaving the shortened vertical splice plate to carry the shear. Now without entering into an extended argument on the subject, does it not seem more rational to splice the web plate so as to resist forces in any direction, and so as to make the splice as strong as the web? This is neither difficult nor expensive. One plate of moderate size on each side of the web with three lines of rivets each side will splice any web (between the limits of the flange angles) in tension, and if properly spliced for tension it will resist bending as well as the unspliced web. The rivets should be spaced at equal distances apart vertically, and their value will vary as their distance from the vertical axis just as the fiber stresses in the web vary, therefore the longitudinal forces in the web travel directly through the splice instead of being deflected up or down to go through the special longitudinal splice plates usually provided. The web plate beneath the flange angles can best be spliced by excess metal in the cover plate, and it is therefore best to locate the splice where there is sufficient excess metal to take care of this.

CLOSURE.

Prof. Turneaure: Mr. Ludlow asked whether we were able to draw any conclusions as to the effective or proper size of stiffener. We have tried to limit our conclusions to reasonable bounds (perhaps we have already overstepped those bounds) and did not undertake to enter into the question of size of stiffener. The data are hardly sufficient to warrant any conclusions on this point.

What seems to be shown by these experiments, and also by those mentioned as having been made at Purdue University, is the small amount of stress in the stiffener. In the case of all stiffeners, except at points of local loading, the stresses are in the hundreds of pounds per square inch. In the stiffeners of the plate girders tested at Purdue University, while the bending stresses appear to run as high as 2,000 pounds per square inch, the axial stress, taking the average of the stresses on the two sides, was in no case in excess of 500 pounds per square inch, and generally lower. With such small stresses the problem of size is one which must be answered from another point of view; that is, how large an angle is necessary to give the web proper stiffness? The observations on the stiffeners were taken somewhat above the center. This should make some difference in the case of stiffeners where there are local concentrations at the end for example, where there is considerable compression, a greater compression would be found near the lower end than the upper, but our observations did not cover that point.

In regard to the sudden breaks in the shear diagram, it should be borne in mind that the assumption with respect to these girders was that the flanges and web plate were equivalent to a solid section, and the edges of the angles were assumed perpendicular to the sides, so as to give an outline bounded by straight lines and right-angle corners. Strictly speaking the curved form would somewhat modify these square off-sets. This however does not affect the general statement as to the distribution of the stress in the body of the web.

In the specification of the American Railway Engineering and Maintenance of Way Association quoted by Mr. Allen, the provision is $12{,}000 - 40\frac{d}{t}$. This is undoubtedly a good working formula, but I call attention to the fact that in this particular girder it would give a strength of 8,000 lbs. per sq. in., whereas the elastic limit strength stress was about 10,000 lbs. per sq. in. Of course the theory used here in the analysis of stresses is the ordinary one; it does not take account of the lateral deformations of the web. Taking these strictly into account, there would be some vertical elongation in the upper half of the girder, and shortening in the lower half. These effects would be very small, and averaging the amount from end to end of the stiffener it would be zero. Consequently this was not taken into account.

THE TECHNOLEXICON

Verein Deutscher Ingenieure
Fernsprecner Amt 1, No. 7165
REICHSBANK-GIROKONTO

BERLIN (NW. 7), CharlottenStraße 4
MIDDLE OF OCTOBER, 1907

The Society of German Engineers have resolved to discontinue the *Technolexicon* because the work has turned out to be expensive beyond all expectation, and because the costs requisite for its accomplishment within the allotted time exceed the pecuniary means available by the Society for this purpose.

All letters and other postal matter concerning the *Technolexicon* please henceforth to send to the undersigned *"Verein Deutscher Ingenieure"*; address: Charlottenstrasse 43, Berlin (NW. 7).

For the furtherance so obligingly bestowed by you upon our Technolexicon-undertaking, we once more beg to thank you most gratefully, and remain,

Yours very truly,

VEREIN DEUTSCHER INGENIEURE,
TH. PETERS, *Director.*

THE CULEBRA CUT OF THE PANAMA CANAL.

A. S. ZINN, M.W.S.E.

Presented November 6, 1907.

Eighty years ago this month the first surveys were started by the Republic of Colombia to ascertain the most eligible line of communication across the Isthmus of Panama, whether by road or canal. The first report was made to Congress of the United States on the construction of a Canal across the Isthmus in 1839.

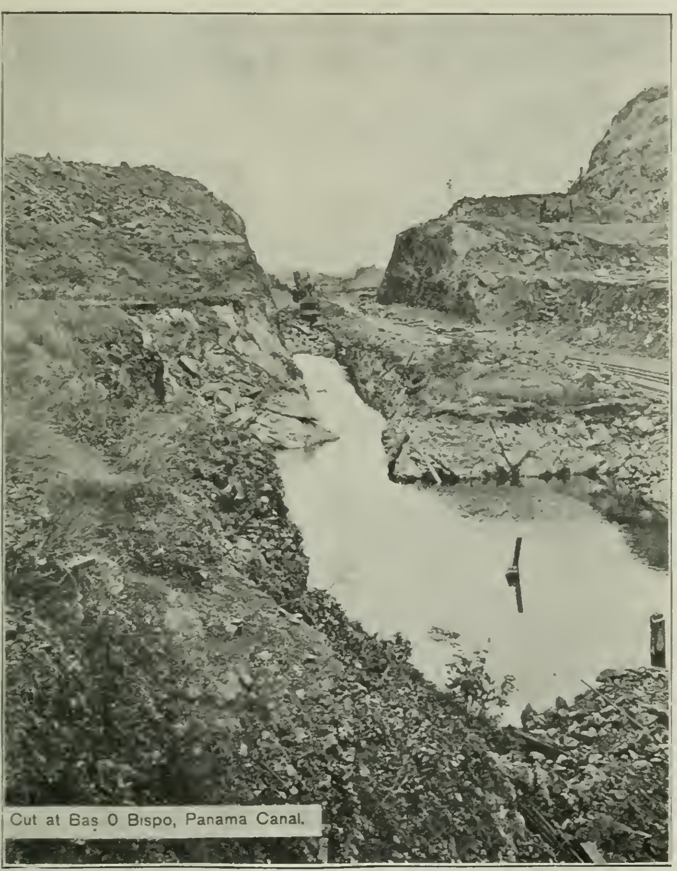
During the next thirty years numerous surveys and reports on the different canal routes were made by Mexico, England, Colombia, France and the United States. In 1875 Captain Lull, U. S. A., was assigned to make a survey and report on the Panama route, and he reported in favor of a route corresponding to a great extent to the present one.

A French Company was organized in 1876 and entered into a contract with the Colombian Government. This contract was modified in 1878; under this latter contract the general route of the proposed Canal was to be determined by an international congress of engineers. It was before the congress of Geographical Science at Antwerp in 1875 that Mr. DeLesseps declared that in his opinion "an inter-oceanic canal, in order to meet all the requirements of commercial navigation, must be constructed on a level as the Suez Canal had been." This opinion of Mr. DeLesseps was destined to prevail four years afterward before the International Congress of Surveys, after a great deal of wrangling among its members as to the best type of canal to construct.

Mr. DeLesseps landed at Colon in December, 1879, and after spending almost two years on preliminary surveys and plans, construction work was started. In 1887 the sea level plan was abandoned and a lock canal plan adopted; and in January, 1889, a receiver was appointed and work abandoned. A new French company was organized and commenced work in 1894 and continued up to May, 1904, when the Americans took charge.

The old French company's work extended over the entire route of the canal from the Atlantic to the Pacific, a distance of 48 miles, while the new French company devoted their whole time—almost ten years—to the Culebra Cut, which is the subject of my paper tonight.

So much has been written about the Panama Canal that I presume all of you are fairly well informed, in a general way, about what has been done and what is going to be done. The work has now progressed so far that an accurate account of it all would fill volumes. An interesting article could be written about the work of the different departments on the Culebra Division alone, such as Constructing and Engineering, Municipal Engineering, Mechanical Engineering, Building and Construction, Material and Supplies, Police Department, Division of Revenues, Division of Schools, Fire Department, Legal Department, Department of Sanitation, Auditing Department, and last, but not least, by any means, the Department of Labor, Quarters and Subsistance. All of these have done splendid work and each form an important part of the great wheel that has started the machinery necessary to the success of a great undertaking. You have all seen pictures and read of the "Great Culebra Cut," and yet you that have not been there may not have a clear idea of the nature of the country, and the general conditions. So it will be my aim to make it as clear to you as possible. The accompanying profile of the Panama Canal will show you the location and limits of the Culebra Cut, extending from the Rio Chagres to the Rio Grande, a dis-



North end of Culebra Cut—at time when U. S. took charge of the work.

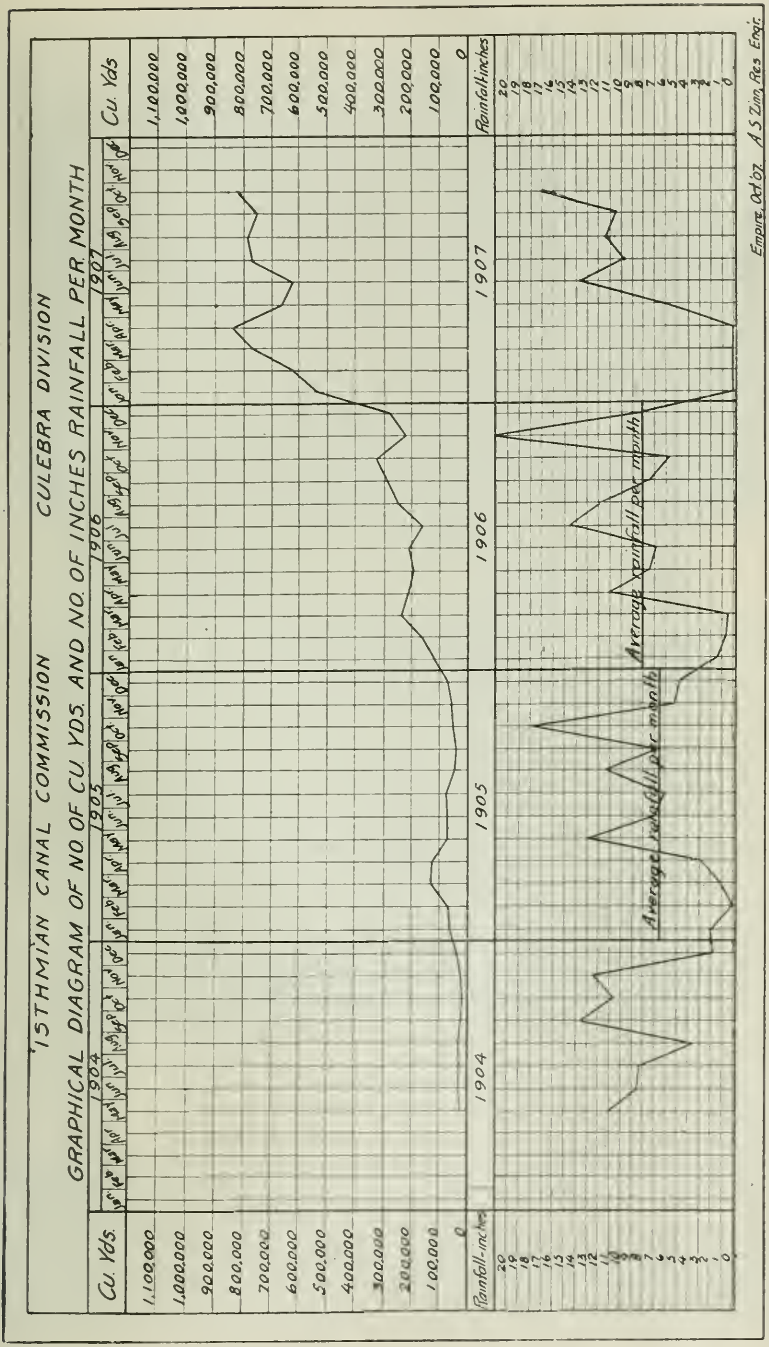
tance of 9¼ miles. The south end is 8 miles from the Pacific Ocean, the Continental Divide 11 ,and the north end of the cut 17¼ miles.

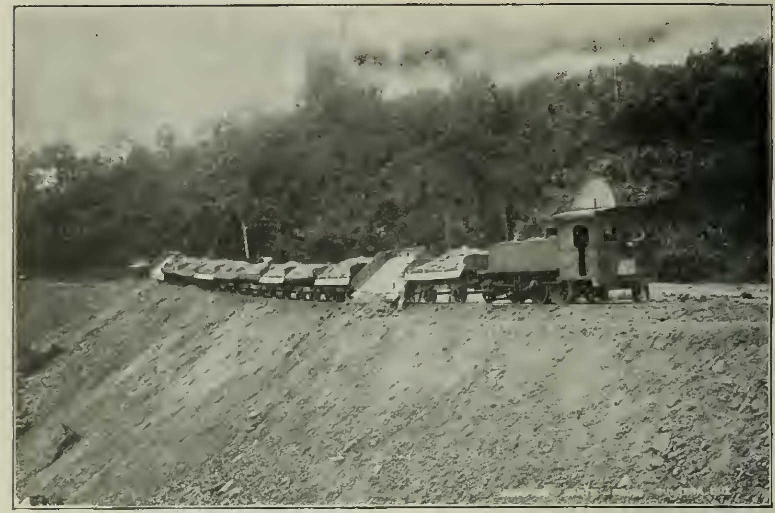
The French records show that about 12,600,000 cubic yards of material was taken out from the Culebra Cut by the old French company, and 10,000,000 cubic yards by the new company; or a total of 22,600,000 cubic yards. Our cross section sheets show correct cross sections every 100 feet at the time the Americans took charge of the work. The natural surface of the ground is well defined on each side, so that we were able to calculate fairly close the quantity of material removed by the French within the limits of the canal prism. We estimated that about 17,000,000 cubic yards were taken out within these limits. On account of the old French company's alignment not corresponding in places with ours, and as they started their work for a seal level canal, their excavations in a few places are beyond our slope line, so that their report of 22,600,000 cubic yards is probably about correct. I have shown for comparison on this profile an approximate estimate of the quantity of material to be excavated after October 1st, 1907. The total being 104,624,000 cubic yards, from which the Culebra Division will be required to move almost one-half, or 47,909,000 cubic yards. Up to October 1st, 1907, the Americans removed a total of 10,189,248 cubic yards, of which 6,360,145 cubic yards was taken out the first nine months of this year, making an average of 706,683 cubic yards per month. If this average is continued, it will be equivalent to 8,840,190 cubic yards per year, or 5 years and 8 months to complete the excavation of the Culebra Cut. October reports just received from Washington show 826,891 cubic yards removed from Culebra Cut, making an average of 718,704 cubic yards per month for first 10 months of this year. It may take, possibly, a year longer to reinforce the side-walls with concrete, in places where there may be a tendency of the rock to disintegrate or slide into the canal.

The accompanying graphical diagrams of the number of cubic yards and the number of inches of rainfall per month since the Americans .took charge will give you a good idea of the progress of the work as well as the amount of rainfall.

You can easily understand why the yardage was so low up to the beginning of this year when I explain the conditions and extent of necessary preliminary work. When the Americans took charge in May, 1904, they found most everything in a wretched condition. outside of the Culebra Division where no work had been done for 15 years the line of canal was so completely obliterated by tropical growth that one would believe no work had ever been done. The Culebra Division showed some signs of life; the French had a few excavators loading material into 4-yard dump cars? These cars were hauled by small Belgium engines and dumped on near-by dumps, the output being about 30,000 cubic yards per month, or about the same as we are now getting out in a single day.

The Americans continued the work with this poor equipment as they had no other. The first thing to look after was to provide

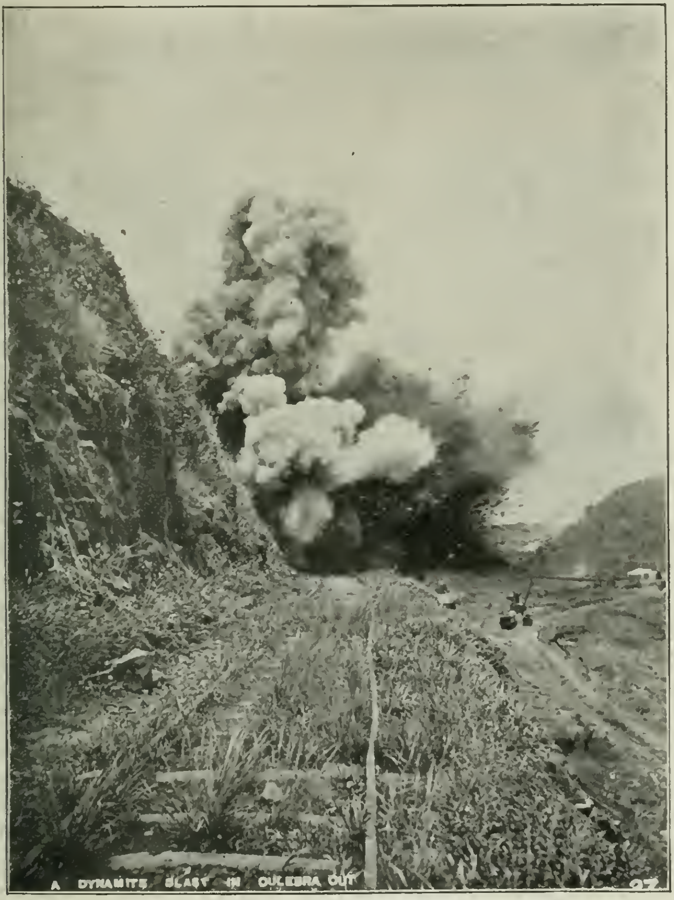

ISTHMIAN CANAL COMMISSION
CULEBRA DIVISION
GRAPHICAL DIAGRAM OF NO. OF CU. YDS. AND NO. OF INCHES RAINFALL PER MONTH
Cu. Yds.
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1904
1905
1906
1907
Rainfall-inches
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Average rainfall per month
Average rainfall per month
Empire, Oct. '07. A S Zinn, Res Engr.



Belgian Engine, with Train of 4-yd. French Dump Cars.

houses and food for the men. The encampments at Bas Obispo, Haut Obispo, Las Cascadas, Empire, Culebra, Paraiso and Pedro Miguel consisted of a number of cheap frame houses for the negro laborers, and a number of better class houses for the whites. These houses had all to be repaired and painted to make them fit to live in. The above-mentioned encampments are now all beautiful little towns, with new and comfortable quarters with modern improvements. The houses are equipped with good furniture, bath rooms and electric lights. The rapid advance in improvements can be best understood by referring to Empire as an example. When I went there a year ago we were having rains about every day and yet we only had about 500 feet of wooden sidewalk, so that we were compelled to walk through mud to reach our quarters; we had no street lights and used oil lamps in our rooms, and there were no places of amusement; so about all we could do at night was to read and tell stories and listen to the rain on the corrugated iron roofs. This soon grows monotonous to anyone and I found that homesickness was sending more good young men back to the States than anything else. The Commission was quick to grasp the situation, and from the beginning have done all in their power to make us comfortable.

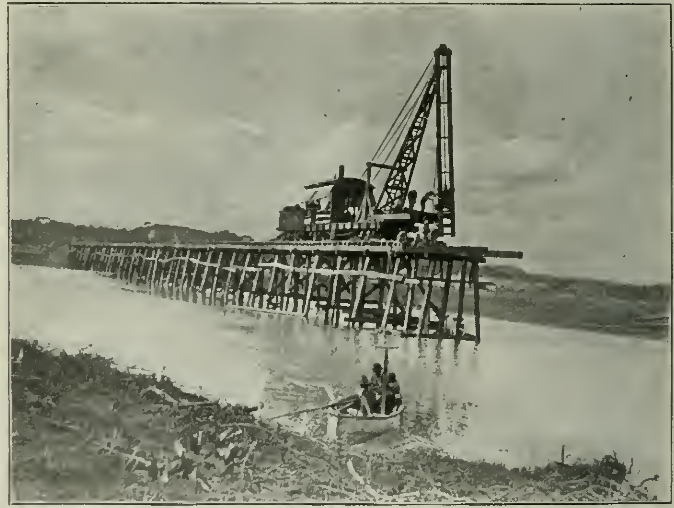
Empire is now a town of about 4,000 inhabitants, including all nationalities. We have wooden sidewalks leading to all the houses; roads have been built and paved; 15 arc lights have been put into service, and most all the houses are now lighted by electric lights. A large Commission hotel has been completed where all white employes can secure a good meal for 30c, and among numerous other improvements are a new school house, post office, court house, base-ball park, and a well-equipped Y. M. C. A. club house, provided with reading rooms, entertainment hall, billiard and pool room, gymnasium, bowling alley, refreshment room and barber shop. I am referring to above to show that it is absolutely necessary in order to hold the right kind of men on important work of this kind, that we must look after their comforts and general welfare or they will be going back to the States on the first boat.



A blast in the Cut—also showing the bad condition of R. R. tracks, as left by the French Co.

Furnishing quarters and provisions for the men was one of the many problems that confronted the first officials on the job. Before any progress in the work could be made machinery and material had to be shipped from the States. Not only did it take time to get the machinery there, but it had to be assembled after it arrived, and all they had to help them put it together was a few old machine shops left by the French. All the railroad tracks were in bad shape and entirely unsafe for modern rolling stock. These tracks have all been replaced with new ties and 70-lb. rail; new tracks have been built to the new dumping grounds until we now have 122 miles of good track to handle material from the Cut, besides the Panama Railroad has been double-tracked in order to help us handle the trains more quickly.

Before going further it may be well to remind you that the type of Canal was not decided on until near the beginning of last year, so that no definite plans for dumps could be made prior to that time. A paper was read before this society about a year ago in which was stated that "more than one man's hair will grow gray before dumping grounds will be found to contain all the material from the Culebra Cut." This problem was solved nine months ago; we now have tracks leading to 15 dumping grounds, with a total capacity of over 50,000,000 cubic yards, which you will see is greater than the number of cubic yards remaining to be taken out. The largest of these dumps is at Tabernilla, which has a total capacity of 15,000,000 cubic yards. The average haul to reach it is 15 miles. The next largest dump is the Sosa-Corozal Dam, with a capacity of 10,000,000 cubic yards, with an average haul of 11 miles. The next largest is at Miraflores, with a total capacity of 8,000,000 cubic yards, with an average haul of 8 miles. The rest of the dumps are of less capacity and near the Canal.


Constructing a trestle at foot of Sosa Corozal dam; preparing for a dump—for material from Culebra Cut.

Along with all this work the building department had to rush the construction of living quarters as rapidly as possible to provide homes for the men that were constantly increasing in numbers. Reservoirs had to be built and pipe lines laid to furnish the houses as well as the steam shovels with water. The sewer and plumbing work had to keep pace with the building, as no one is allowed to occupy a house until it is connected with water and sewer pipes and accepted by the Sanitary department. And in order to assemble the steam shovels and other machinery and look after repairs, the construction of machine shops had to be started at once.

As our rolling stock was also constantly increasing, yards had to be constructed for handling the cars; coal chutes, cinder pits, water tanks, and cranes also had to be built. It was also important to build air compressors, and we now have air compressor plants at Las Cascadas, Empire and Rio Grande of 4 compressors each. Each compressor having a capacity of 2,500 cubic feet of air per minute at 100-lbs. pressure. This compressed air is fed into one line of 10-inch extra heavy pipe 9½ miles long with leads of 6-in. and 4-in. diameter running into the Canal prism to drive the drills and into the shops for the machinery.

In addition to above air pipe line, we have 14 miles of water pipe and 12 miles of sewers.

The number of men now employed on the Culebra Division in the Mechanical Department is 1,316 and will be increased about 400 men as soon as the new shops at Empire are completed.

Referring now to accompanying contour map and profile of the Culebra division, you will note the alignment of the Panama Canal and Panama Railroad and the location of all encampments. Beginning at the north end of cut at Bas Opispo, is located a stone crusher of 1,000 cubic yards capacity per day. The stone is taken from the rock cut at that point, and after crushed is used for ballasting track, and also for concrete. At Las Cascades is located a 20-pocket coal chute with gasoline hoists, also engine house, double-track cinder pits, machine shops, air compressor plant, and a large railroad yard for handling cars from the Cut. At Empire, the next largest shops on the Zone are nearing completion. Repairs to steam shovels, locomotives and other machinery are made here. An electric light plant for providing lights to Empire and adjacent encampments is also located here, as well as an air compressor plant.

At Culebra are located the general offices, in which are the Chief Engineer and heads of departments. Between Empire and Culebra is an engine house and large planing mill and lumber yard.

At Rio Grande, near Culebra, is an air compressor plant and engine house, and railroad yards.

At Paraiso are machine shops for locomotives and steam shovel repairs.

At the south end of the Cut, at Pedro Miguel, is a large clearance yard for handling work trains from the Cut. We also have a 20-pocket coal chute with gasoline hoist, a very large two-track cinder pit and engine house. Excavation is now being made at this point for the locks.

It was absolutely necessary to construct all the above-named shops, buildings, engine houses, yards, etc., in order to maintain and handle our large equipment. The equipment reached its maximum, with the exception of cars, the first part of this year. We could use more steam shovels but it would not be economical, besides it has been demonstrated beyond a doubt that with the present equipment the Culebra Cut can be completed in about 6 years or before the completion of the locks and dams outside of the Culebra division.

The total number of men employed in the Engineering and Construction Department of the Culebra division is 10,189, of which about 950 are Americans and the balance are Jamaican and Martinique negroes, Spaniards, Italians, Hindoos and a few Panamaians.

The equipment assigned to the Culebra division consists of the following:

47	Steam Shovels.
17	Lidgerwood Unloaders
18	Spreaders
4	Track Throwing Machines
224	Locomotives
2092	Cars
126	Steam and Air Drills
93	Mechanical (or Churn) Drills
1	Rock Crusher
2	Wrecking Cranes
12	Pile Drivers
1	Clam-Shell Dredge

This equipment is never all used at the same time; there is always some equipment in the shops for repairs. During the months of August and September, the daily average number of steam shovels at work was 41, and the time lost on account of rain and other unavoidable causes was 40%; yet the average number of cubic yards loaded by each shovel per month was 18,300 cubic yards. About 53% of the material had to be blasted before it could be handled by the steam shovels. The drilling and blasting is kept ahead of the shovels to avoid any delay. The drilling and blasting is one of the important parts of the work. To give you an idea how much work in this line is done in a month I will quote from August report. During this month there was drilled by:

Steam and Air Drills	53,500 lin. ft.
Well or Mechanical Churn Drills	32,559 lin. ft.
Hand Drilling	12,632 lin. ft.
Making a total of	98,701 lin. ft.

Or 18.7 miles.

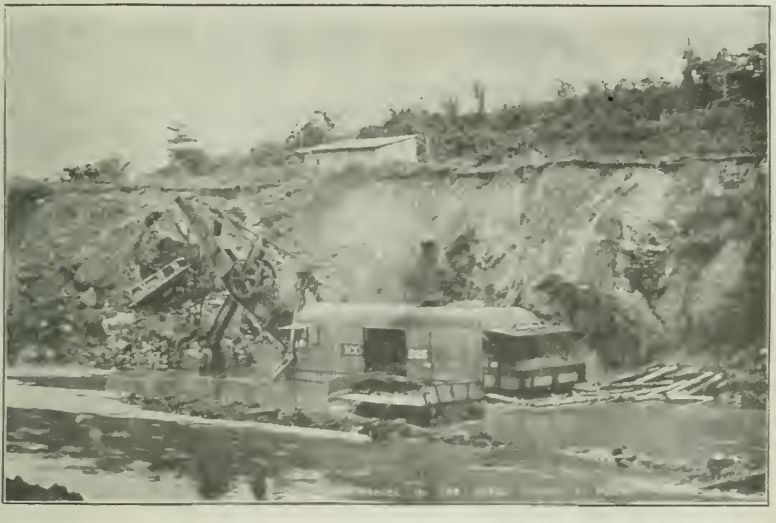
The explosives used during the month amounted to:

Dynamite	247,550 lbs.
Black Powder	400 lbs.
Making a total of	247,950 lbs.

Or about 124 Tons.

The shovels that have been used so far are the Bucyrus (70 and 95 ton type). The 70 ton type having 2½ and 3½ yard buckets, and the 95-ton, 5 cubic yards.

The highest record made so far by any one shovel was 217 cubic yards in one day. The above average of 18,300 cubic yards per month will seem very low to you who have seen two and three times that much loaded, but you must consider the conditions under which our men work. Almost every day in the year between 10 a. m. and 3 p. m. the temperature is from 120° to 130° in the Sun. The rainy season extends from about the middle of April to the end of the year. During this time it rains part of 'most every day, and now and then we have a rain of 2 to 3 inches in as many hours. The water then rushes into the canal and floods everything; shovels are tied up, and tracks placed in such bad condition that it is necessary to set a large gang



Steam shovel flooded in the Canal by a big rain.

dippers, and the helpers around the shovels are constantly working in mud. Then, we are troubled with slides. Just before I left we had of men to work on the track to get them in fit condition for the trains.

The blasted material can be loaded alright during the rainy season but the clays are so sticky that it is hard to get it to slide through the a slide from the east side of cut opposite Station 1820 that started to break over a thousand feet from the canal and moved so rapidly that it covered one shovel with mud before the men had time to pull it out. The whole mass of saturated clay was over 400 feet wide and continued to move for several days until it spread over the track and shut off traffic at that end of the cut for four days. This whole mass of about a quarter of a million cubic yards will be taken out next dry season, so that no more trouble is expected at that point, but there are several more smaller slides that will give us trouble.

Like all jobs of this kind one of the most difficult parts of it is the handling of trains in such a way as to keep the shovels busy. The transportation is handled by Superintendent of Transportation and the Superintendents of Construction. So far it has been impossible to always get the empties back to the shovels in time, and you will find the same trouble very often on similar work in the States. It is necessary to operate the trains on grades that will not allow more than 17 to 20 cars to the train, and to handle as we are now doing about 31,000 cubic yards per day, means about 2,000 loads and as many empties requiring about 120 trains each way per day. 33% of the material is now hauled to the dumping grounds at Tabernilla, a distance of 15 miles over the Panama Railroad, where delays happen now and then on account of main line traffic, and occasionally a wreck, so that it is impossible to always avoid delays. The despatchers are aided in their work by a number of telephone stations along the cut; these 'phones are also very useful for the foremen and officials to communicate with men along the cut and are connected with the general offices and division offices, so that we are always in touch with the work, even when in the office.

Four kinds of cars are used; large Western dumps with a capacity of 20 yards, small Western dumps with capacity of 12 yards, French dumps with capacity of 4 yards, and side flats with capacity of 20 yards. The Western and French dump cars unload at either side. The side flats have a 3-ft. permanent side-board at one side and the opposite side has a 14-inch extension to floor of car, so that when the dirt is plowed off with side plow, the material will not roll back on the rail. These plows are pulled by 1½ inch cables connected with the Lidgerwood unloader that unloads the train in 10 minutes or less, depending on condition of material.

Most of our large dumping grounds are started by first driving a temporary trestle about 20-ft. high across low ground, and then the trestle is filled and embankment widened out as far as the wings to the spreaders will permit. The track is then shifted from trestle to edge of new embankment, and the same thing repeated over and over again until some of our dumps are 400 feet wide. The track settles down into the mud so that it required a great many men to shift the track. This difficulty has been overcome by using a track-shifting machine, invented by W. G. Bierd, General Manager of the Panama Railroad at that time. One of these machines with an engineer, fireman and ten laborers, will do the work of 350 men. This is really nine lifts

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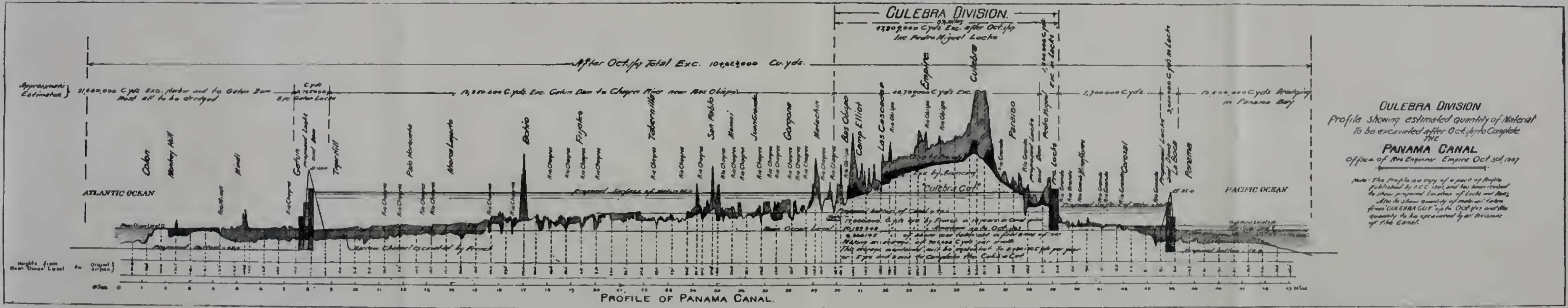


PROFILE OF PANAMA CANAL.

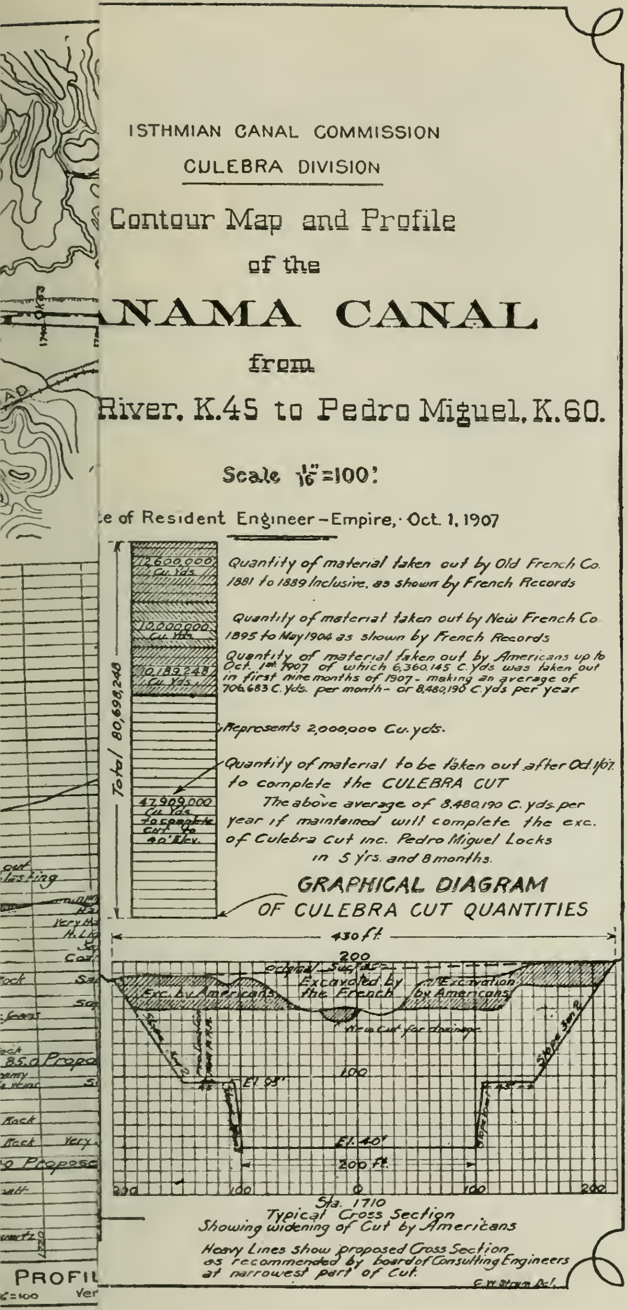
CULEBRA DIVISION

Profile showing estimated quantity of Material to be excavated after Oct. 1/07 to Complete the

PANAMA CANAL

Office of the Engineer Empire Oct. 30, 1907

Note: The Profile is a copy of a part of Profile published by I.C.C. 1907, and has been revised to show proposed location of Locks and Dams. Also to show quantity of material taken from "CULEBRA CUT" up to Oct. 1/07 and the quantity to be excavated by all Divisions of the Canal.


ISTHMIAN CANAL COMMISSION
CULEBRA DIVISION
Contour Map and Profile
of the
NAMA CANAL
from
River, K.45 to Pedro Miguel, K.60.
Scale 1/16" = 100'.
e of Resident Engineer – Empire, Oct. 1, 1907
2,600,000 Cu. Yds.
Quantity of material taken out by Old French Co. 1881 to 1889 Inclusive, as shown by French Records
10,000,000 Cu. Yds.
Quantity of material taken out by New French Co 1895 to May 1904 as shown by French Records
10,189,248 Cu. Yds.
Quantity of material taken out by Americans up to Oct. 1st 1907 of which 6,360,145 C. Yds was taken out in first nine months of 1907 – making an average of 706,683 C. Yds. per month – or 8,480,190 C. Yds per year
Represents 2,000,000 Cu. yds.
Quantity of material to be taken out after Oct. 1/07 to complete the CULEBRA CUT
47,909,000 Cu. Yds. to complete cut to 40' Elev.
The above average of 8,480,190 C. yds. per year if maintained will complete the exc. of Culebra Cut inc. Pedro Miguel Locks in 5 yrs. and 8 months.
Total 80,698,248
GRAPHICAL DIAGRAM OF CULEBRA CUT QUANTITIES
430 ft.
200
Original Surface
Exc. by Americans
Excavated by the French
Excavation by Americans
New Cut for drainage
El. 95'
100
El. 40'
200 ft.
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Sta. 1710
Typical Cross Section
Showing widening of Cut by Americans
Heavy Lines show proposed Cross Section as recommended by board of Consulting Engineers at narrowest part of Cut.
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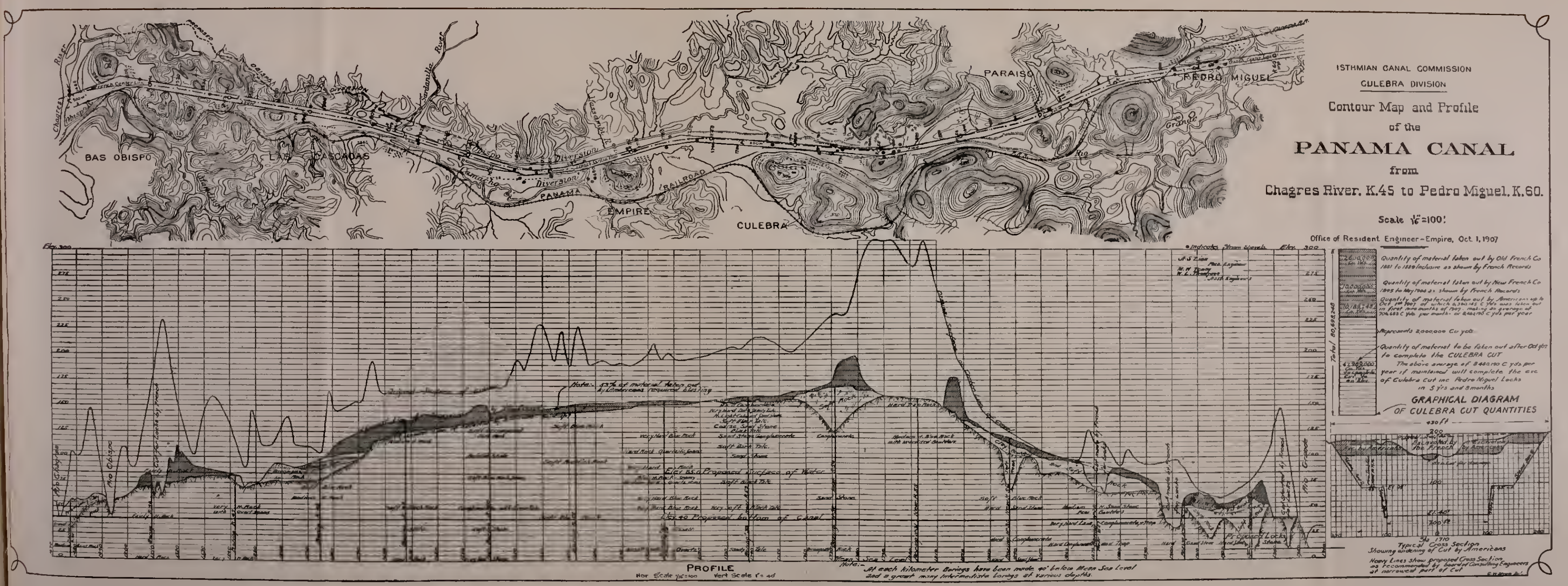


ISTHMIAN CANAL COMMISSION

CULEBRA DIVISION

Contour Map and Profile of the

PANAMA CANAL

from

Chagres River, K.45 to Pedro Miguel, K.60.

Scale 1/16"=100'.

Office of Resident Engineer—Empire, Oct. 1, 1907

Quantity of material taken out by Old French Co 1881 to 1889 inclusive as shown by French Records

Quantity of material taken out by New French Co 1895 to May 1904 as shown by French Records

Quantity of material taken out by Americans up to Oct 1st 1907 of which 6,300,145 C yds was taken out in first nine months of 1907, making an average of 706,683 C yds per month or 8,480,190 C yds per year

Represents 2,000,000 Cu yds

Quantity of material to be taken out after Oct 1st 07 to complete the CULEBRA CUT

The above average of 8,480,190 C yds per year if maintained will complete the exc of Culebra Cut inc Pedro Miguel Locks in 5 yrs and 8 months

GRAPHICAL DIAGRAM OF CULEBRA CUT QUANTITIES

Sta 1710

Typical Cross Section Showing widening of Cut by Americans

Heavy Lines show proposed Cross Section as recommended by board of Consulting Engineers at narrowest part of Cut

PROFILE

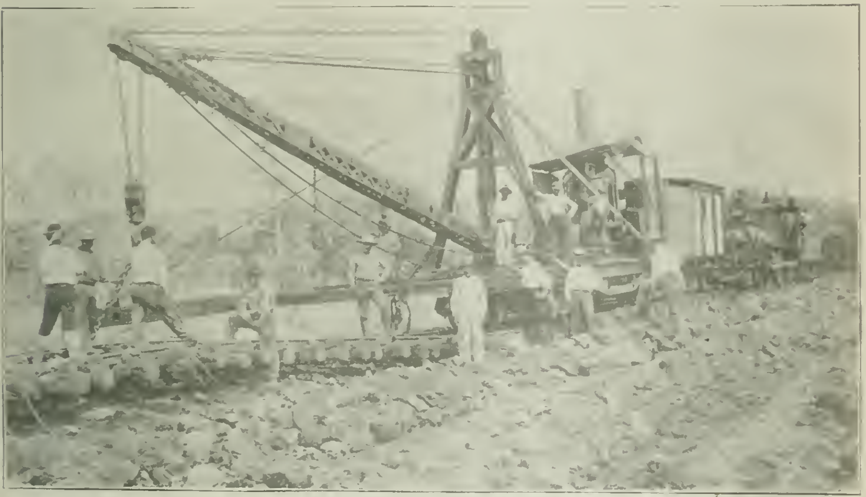
Hor Scale 1/16"=100 Vert Scale 1"=40

Note:—At each kilometer Borings have been made 40' below Mean Sea Level and a great many intermediate borings at various depths.

the only new kind of a machine on the whole job. This machine lifts the track as well as shifts it.

The spreaders used are the McGann and the Jordan, equipped with air and are made much stronger in every way than any I have ever seen in the States. It is necessary to have the wings extra strong as we handle a great deal of stone along with the dirt. Some of these stones are from 3 to 5 feet in diameter. An ordinary spreader such as has been used on Chicago track elevation work would not answer the purpose at all.

Referring again to plan and profile, you will note from contours that the line of canal passes through a very hilly country throughout the 9¼ miles. At Station 1790 the original line selected by the French passed over a saddle at an elevation of 312 feet above mean sea level. Just east of this saddle, is Gold Hill, at an elevation of 655 feet, and west of same is Contractors Hill, at an elevation of 400 feet. The French cut the saddle down 152 feet; this place is known as the "Big Cut," and is where most of the pictures have been taken to show Culebra Cut, while in fact, as stated before, Culebra Cut is 9¼ miles long. At the present stage of the work, it varies in depth from nothing at each end to 152 feet at Gold Hill. The deepest cut yet required to reach the proposed bottom, you will note, is at Station 1775, where it will require a further cut of 130 feet. Soon after work was started by Chief Engineer Wallace, borings were made at each kilometer 40 ft. below mean sea level, and a great many intermediate borings have been made since that time at various depths, to determine the nature of the material. The results of these borings are shown on profile, and you will see that most of our work hereafter will be in rock.



Track Shifting Machine

At each side of the deepest part of the cut the French left a barrier about 30 ft. high, as shown on profile. The first work of the Americans was to take these out so that tracks on which to haul material could be carried through the cut. It would appear from the profile that we have not accomplished very much work compared with the French. In order to make it clearer to you I have shown at right of profile a true cross section taken at Station 1710. The French made a cut, varying in width from 50 feet to 150 feet, throughout the entire distance. From one to three running tracks have been laid near the center, with a loading track at each side, with connections with the running tracks. A line of shovels was started at each side, as shown by full circles on plan, and as the cut was widened the loading tracks were shifted to accommodate the shovels. The cut is now completed, as shown on cross section, to full width at top for about three-fourths the distance, and lower cuts have been started. These lower cuts will be widened the same way, until the slope lines are reached, and so on, with succeeding cuts until all the material is removed. When the cut is completed, it will vary in width from 200 ft. to 500 ft. at the bottom, with slopes as shown. On account of the water running into the cut, we keep a drainage channel, made with clam shell dredge, near the center of the canal, with side drains, so as to keep the water away from the shovels and tracks as much as possible. And this brings up the Engineering problem:

What will we do with the water when we get down near the bottom of the canal? The proposed bottom of the canal, at an elevation of 40, is the same as the bottom of the Chagres River. This will probably be handled in one of two ways: In either case, a barrier will have to be left to the last moment at the south side of the Chagres River, to keep that water out, and that which collects in the cut from side drainage could be pumped over the barrier, or we can make a small channel with a fall of about 2 ft. to the mile, commencing at this barrier near the Chagres and extending it through the canal to the south end of the cut at Pedro Miguel, where the bottom of the Rio Grande is at an elevation of 18 ft., and from there the water will flow to the Pacific Ocean. The French engineers recognized the importance of keeping the water out of the canal during construction and completed most of the diversion work along the west side, the most difficult of which was the cutting of a tunnel 600 ft. long through a solid rock hill near Bas Obispo. Plans for the completion of the diversion work along this side of the canal have been approved by the Chief Engineer and work has been started and will be completed next dry season. The French also started a diversion channel along the east side of the canal, and it was their intention to carry it across the canal near Las Cascadas in a steel acqueduct. (All the steel for this structure is on the ground, but is so destroyed from long exposure that it is almost worthless.) Plans have also been approved by the Chief Engineer for a diversion channel along the east side of the canal, to carry the waters of the Obispo, Massambix and Sardanilla Rivers, and their tributaries, to the Chagres on a route, as shown in dotted line. The total length of this channel will be 4½ miles, of which 1½ miles is now completed. In order to carry all the water, the channel is being constructed to take care of a flow of 6,000 second feet. The last mile of the north end of this channel will be difficult of construction. A number of dykes reinforced with creosoted sheet piling will be constructed, and the whole line is made up of short tangents connected by 18° curves, through a thick jungle, and the deepest cut is to be 87 feet with 95% rock.

After these diversion channels are completed, the only water that will run into the canal will be that which falls on the area between these diversion channels.

The dash and dotted line shown along the canal route represents the French center line, and is a series of tangents connected by easy curves. This is practically the same route adopted by the Board of Consulting Engineers, except in place of curves there are angles, with a wide turning basin at each angle. There are nine of these angles in the 9¼ miles, the longest tangent being 9,532 ft. As you will note by typical cross section, there is to be a 45-ft. berm at an elevation of 95 ft. on each side of the canal. Along the east berm will be built the new Panama Railroad. The object in placing it on that side is to avoid crossing the canal. The present old line west of the canal will be taken up as soon as the canal is completed. When the Americans took charge of the French center line was well-defined by monuments set at most of the kilometers, and along each side away from the canal were found a great many concrete bench marks, and they have been found accurate.

The location selected by the French is about the most practical and economical route that could have been selected, and their maps and profiles now in our possession are as neatly gotten up as you will find anywhere; in fact, most of us would not allow a draughtsman to put so much time on a map.

You have all probably read a few criticisms on the canal work. I only care to mention one that referred to estimate of yardage on the Culebra Division. This criticism, like some others on the work outside of the Culebra Division, was misleading. It stated that it was impossible to make up a monthly cross section estimate of three quarters of a million cubic yards in time to cable the yardage to Washington the 1st or 2nd of each month, as is being done, and that our measurements are "not excavation in place, but car measurements." I wish to correct this by saying that our estimates are accurately calculated from cross sections taken every 50 ft., behind each shovel, and are measurements in excavation and not "car measurements." I will explain how our estimates are gotten out quickly. The Resident Engineer's office at Empire is about the middle of the division, with two parties to handle the railroad, stadia and diversion work. We then have an Assistant Engineer's office at Paraiso and one at Las Cassadas. Mr. M. W. Tenny is Assistant Engineer at Paraiso, with a party of 24 men, of which 12 are negroes rated as machetemen, who do the chaining and keep the cross section lines and base lines cleared of tropical growth. Mr. W. L. Thompson is Assistant Engineer at Las Cascadas with about the same number of men and has the same kind of work, each of them having about 4½ miles of canal work. Their instrumentmen keep the cross-sectioning close up behind each shovel, so that the cross sections and most of the estimates are completed the evening of the last day of each month. The cross sections are accurately platted and the estimates are generally completed and checked by planimeter by 3 p. m. on the 1st of each month. As soon as the totals are known, it is telephoned to my office, then to the Division Engineer's office, and from there to the Chief Engineer, who cables it to Washington. The October estimate was cabled to Washington Nov. 2nd, and reached me here by mail Nov. 4th. The cross section estimates are then made up in detail by the Assistant Engineers, showing classification of material. Five typewritten copies are then made in the Resident Engineer's office and forwarded to the Division Engineer and Chief Engineer for permanent record.

Engineers Cross-sectioning for Monthly Estimate

The Superintendents of Construction make up daily car reports so that each evening we do not only know the exact number and kind of cars handled, but the approximate number of cubic yards to date by estimating so many cubic yards for each kind of car. The total car measurements for the month agree reasonably close with the cross section estimate.

On each side of the canal we have permanent base lines parallel to the center line, and from 300 ft. to 400 ft. away, depending on local conditions. These base lines are accurately monumented about every 500 feet, with intermediate stakes every 100 ft. All cross sections are tied on to these base lines. Every 100 ft. we have cross section lines cut through the jungles out to the base lines, and in many cases from 400 ft. to 1,200 ft. beyond, to aid us in making up our contour maps. These cross sections are platted on mounted cross section sheets about

Engineers Connecting Cross-section to Base Line—300 ft.—and Parallel to Center of Canal. Base Line at White Mark.

7 ft. long and colored in different colors to show the progress of the work each month, and will be valuable sheets for future reference. You can easily see the difficulty by referring to views, one showing an almost perpendicular cut behind a steam shovel, and the other view shows the men checking up their work with the base line 75 ft.

above the bottom of the shovel cut. You will also note the tropical growth; this grows so rapidly during the rainy season that it is necessary to clear our cross section lines and base lines about every month in order for the levelmen to see the rod.

You will now see from my description of the work that it is handled in about the same way, and with about the same kind of equipment that would be used on a big railroad cut in the States; so, after all, there is nothing new or very difficult in the excavation and handling of material from Culebra Cut—just a big job! that's all.

The Big Cut near Culebra, soon after the U. S. Forces took charge of the work.

N. A. SAGER, M.W.S.E.
August 30, 1907.

Nelson A. Sager was born in Port Hope, Ontario, April 22, 1854, where he spent his boyhood days and passed through the grammar school. He next attended Cobourg (Ontario) College where he studied civil engineering. After graduation he entered the service of the Toledo & Ohio Central R. R. (now the Hocking Valley R. R.) as assistant engineer in the maintenance of way department. One of his achievements here was a complete re-survey of the entire line and the inauguration of comprehensive maps of the company's right-of-way. Later he superintended the erection of new bridges and buildings and the construction of several branch lines.

In 1890 he took service with the World's Columbian Exposition as assistant engineer and had charge of the construction of the main part of the Manufacturers' Building. After the completion of the

World's Fair he was engaged as an assistant engineer for the City of Chicago, and had charge of the construction of many important engineering works built by the city of Chicago since 1893, the most notable of which was the intercepting sewer system. Mr. Sager took an active part in designing the details of this great system and later was in local charge of the construction of the most important trunk lines.

In 1891 Mr. Sager was selected by a party of capitalists to make a technical examination of the possibilities of irrigation for the barren northwest portion of Kohala on the Island of Hawaii. This mission was successfully accomplished in four months, after which he resumed his duties as assistant engineer for the City of Chicago.

The contruction of the sewage pumping station at 39th street and Lake Michigan, with breakwater and intake, was erected under Mr. Sager's personal supervision and will stand as a monument to his integrity and ability as a civil engineer. In 1906 he was placed in charge of the construction of the sixteen foot conduit in Lawrence Ave., leading from the Lake to the North Branch of the Chicago River, but before its completion was placed in charge of the entire Intercepting Sewer Division, reporting to the City Engineer.

Early in August, 1907, he contracted a cold which in the stress of business was neglected too long. It developed into neuralgia of the stomach, and after three weeks of intense suffering he breathed his last on Friday, August 30, 1907.

He was married February 14, 1900, to Miss Clara E. Armstrong, who survives him together with their nine-months-old daughter.

Mr. Sager was a Knight Templar and a member of the new Illinois Athletic Club, and also an active member of the Western Society of Engineers.

There was not a truer nor more generous friend than Nelson A. Sager, and his many friends will miss the influence of his strong personality.

(Signed) J. H. SPENGLER,
C. D. HILL,
W. A. SHAW,
Committee.

J. C. Darst, M.W.S.E.
September 5. 1907.

John Clark Darst was born in Troy, Miami County, Ohio, in 1851. His father was Henry H. Darst, M. D., a prominent and respected citizen of the Miami Valley. His mother was a Clark. Her family have long been residents of the same locality. Mr. Darst's early life was spent in and about Tippecanoe, Ohio. From there his father's family moved to Toledo, Ohio, where Mr. Darst resided with his parents. He graduated at the Wesleyan College at Delaware, Ohio, in 1872, after which he spent a year at Harvard in special study. After finishing his education he became identified with the Smith Bridge Company, and in 1881 formed a copartnership with A. J. Sprague, H. A. Williams and Mr. Eckert, operating as the Massillon Bridge Works, of Massillon, Ohio. This was later incorporated as the Massillon Bridge Company, Mr. Darst being one of the principal stockholders and a director. Removing in 1883 to Chicago, he assumed the control and management of the western business for his firm and later for his Company, in which position he continued until 1900 when the New Toledo-Massillon Bridge Company was formed. Mr. Darst then disposed of his interests and formed the contracting firm of Darst and Hughes, of Chicago, Illinois, of which he was senior member. This business was later incorporated as the Continental Bridge Company, of which Mr. Darst was Treasurer until the time of his death. During his business career Mr. Darst had charge of the construction of many notable structures in Illinois and adjacent states, among which were the Lake Street Viaduct; steel work for the First Regiment Armory; bridges at the World's Fair grounds, Chicago; State Street bridge at Rockford, Ill., Chicago Street bridge at Elgin, Ill., and many others.

He died leaving considerable estate. During his life he was always ready to help his friends, especially the young men. He was of a cheerful, happy disposition, and his many friends sincerely mourn his loss. He was noted for his loyalty and unswerving integrity.

Of his immediate family he leaves a sister, Mrs. Hyatt, of Toledo, and her three children, two sons and a daughter. Mr. Darst was active until the day of his death. He was stricken with hemorrhage of the brain and died in a few hours. He was buried in Woodlawn Cemetery, Toledo, Ohio, September 9, 1907, the burial services being conducted by the Toledo Commandery Knights Templar, of which he was a member for many years.

He became a member of the Western Society of Engineers, June 5, 1900, and was also a member of the Illinois Athletic Club.

(Signed) HORACE E. HORTON,
ANDREWS ALLEN,
W. H. RONEY,
Committee.

PROCEEDINGS OF THE SOCIETY

MINUTES OF REGULAR MEETING, November 6, 1907.

A regular meeting of the Society (No. 615) was held in the Society rooms Wednesday evening, November 6th. The meeting was called to order at 8:15 p. m., with President Abbott in the Chair and over 100 members and guests present. The minutes of the meeting of October 2nd and October 16th were read and approved.

The Secretary reported from the Board of Direction the election into membership of the following:

	Grade.
Otto S. Hansen, Chicago	Junior
S. L. Pierce, Chicago	Junior
Charles K. Mohler, Chicago	Active
A. J. Schafmayer, Chicago	Junior
Russel J. Mershon, Chicago	Active
C. W. Shepherd, Chicago, transfer from Junior to	Active
J. T. Walbridge, Chicago	Junior
Harold K. Weld, Elgin, Ill.	Junior
Forrest S. Harvey, Chicago	Junior
Charles C. Lemmon, Elmhurst, Ill.	Junior
James R. MacKnight, Chicago	Junior
William K. Hatt, Lafayette, Ind.	Active
John W. Kendrick, Chicago	Active
H. G. Macdonald, Chicago	Junior
V. E. Ellstrom, Evanston, Ill.	Junior
Edgar W. Block, Chicago	Active
Edwin A. Carter, Chicago	Active

Also that the following had applied for membership:

Richard M. Gerety, Chicago	Active
C. W. Birch-Nord, Chicago, transfer from Junior to	Active
John T. Mountain, Chicago, transfer from Junior to	Active
Homer Thomas, Chicago	Active
T. Bright Carrick, Dorena, Mo.	Active
Charles H. Freeman, Chicago	Associate
William H. Vincent, New Orleans, La.	Junior
Albert B. Mills, Chicago	Junior
Norman M. McGillivray, Chicago	Junior
Maro Johnson, Chicago, transfer from Junior to	Active
Archibald O. Walker, Chicago	Active
N. H. Jacobsen, Chicago	Junior
A. K. Sjolander, Chicago	Junior
Judson, Lattin, Chicago	Active
Hubert C. Ellis, Chicago	Junior
George T. Bunker, Chicago	Active
Horace S. Baker, Chicago	Active

The Secretary announced that petitions, in due form and properly signed, had been received for certain amendments to the Constitution and By-laws; that those amendments had been printed and sent out to the membership and it was now in order to discuss the matter and to offer amendments thereto. There was no discussion and no amendments were offered, so it was ordered that the amendments be printed and sent out to be voted on by means of a letter ballot, the ballots to be canvassed and the results announced at the next regular meeting of the Society, to be held December 4, 1907.

The Secretary also announced that the Entertainment Committee had under way arrangements for a "Ladies' Night" for Saturday, November 16th, when Mr. J. W. Alvord would give an illustrated lecture on some of the engineering matters seen this past summer when in Mexico in attendance at the convention of the American Society of Civil Engineers.

There being no further business to bring before the meeting, Mr. A. S. Zinn, M.W.S.E., was introduced, who addressed the meeting on "The Culebra Cut and the Progress of the Work."

Discussion and remarks followed from President Abbott and Messrs. T. L. Condron, T. R. Cummins, R. C. Smith, Willard Beahan and others.

The meeting adjourned about 10 p. m.

EXTRA MEETING, November 20, 1907.

An extra meeting of the Society (No. 617) was held Wednesday evening, November 20th, 1907.

The meeting was called to order about 8:20 p. m. with President Abbott in the Chair and about 45 members and guests present, including some five or six ladies, notwithstanding a stormy day and evening.

There was no business to bring before the meeting, so Mr. Linn White, M.W.S.E. was introduced who read his paper on "The Construction of Small Parks in Chicago." This related more particularly to the work done by the South Park Commissioners. A large number of lantern slides, many being colored, illustrated the paper and added to the interest of the evening.

Remarks and discussion followed from President Abbott and Messrs. A. C. Schrader, T. L. Condron, J. H. Warder, M. K. Trumbull, C. K. Mohler; with a closure by Mr. Linn White.

The paper by Mr. J. W. Schaub on "Railway Track in the Past and Its Possible Development in the Future," which had been printed and sent out since it was first delivered before the Society, was not brought up at this meeting as had been expected, as the hour was too late.

The meeting adjourned about 10 p. m.

REGULAR MEETING, December 4, 1907.

A regular meeting of the Society (No. 618) was held in the Society Rooms Wednesday evening, December 4, 1907.

The meeting was called to order at 8:20 p. m. with President Abbott in the Chair and about 90 members and guests present.

Mr. M. K. Trumbull offered a motion that the Chair appoint a Committee of three to canvass the letter ballots on the Amendments to the Constitution and By-laws and to report to the meeting. The Chair appointed Messrs. R. F. Schuchardt, James N. Hatch and William B. Ewing, a Committee to perform this duty and report to the meeting.

The Minutes of the meetings held November 6th and 20th were read and approved.

The Secretary reported from the Board of Direction that the following had been elected into membrship at their meeting of December 3rd:

	Grade.
Richard M. Gerety, Chicago	Active
Carl W. Birch-Nord, Chicago, transfer from Junior to	Active
John T. Mountain, Chicago, transfer from Junior to	Active
Homer Thomas, Chicago	Active
T. Bright Carrick, Dorena, Mo.	Active
Wm. H. Vincent, New Orleans, La	Junior
Albert B. Mills, Chicago	Junior
Norman M. McGillivray, Chicago	Junior
Maro Johnson, Chicago, transfer from Junior to	Active
Archibald O. Walker, Chicago	Active
Noah H. Jacobsen, Chicago	Junior
Axel K. Sjolander, Chicago	Junior
Judson Lattin, Chicago	Active
Hubert C Ellis, Chicago	Junior
George T. Bunker, La Grange, Ill.	Active

Also that applications for membership had been received from the following:

Thomas H. Tapley, Chicago	Active
Arthur N. Johnson, Springfield, Ill.	Active
W. F. M. Goss, Champaign, Ill	Active
Horace S. Baker, Chicago	Active
George T. Stewart, McComb, Miss.	Active
Frank S. Clark, Bedford, Ind.	Active
Wm. S. Fulton, New Orleans, La., transfer from Junior to	Active

Also that petitions for nominations for officers of the Society for 1908 had been tabulated by the Secretary and approved by the Board of Direction as follows:

Nominations for Officers of the Society for 1908.

For President.
Andrews Allen.
J. W. Alvord.
C. F. Loweth.
For First Vice-President.
J. W. Alvord.
E. N. Layfield.
G. M. Wisner.
For Second Vice-President.
Geo. A. Damon.
P. Junkersfeld.
W. S. Monroe.
A. N. Talbot.
For Third Vice-President.
D. W. Mead.
James McL. White.
P. B. Woodworth.
For Treasurer.
A. Reichmann.
For Trustee.
H. N. Elmer.
L. E. Ritter.
J. W. Schaub.

The Committee to canvass the letter ballots on the Society vote as to the Amendments to the Constitution and By-laws presented their report as follows:

Amendment to the Constitution. Article III, Sec. 4, relating to age limit of Junior members, and also amendment to By-laws, Article VI, Sec. 1, pertaining to the same:
Affirmative votes received 149
Negative votes received .... None

Amendment to By-laws in Article III, Sec. 2, creating a standing committee on amendments, and Articile III, Sec. 8, pertaining to the duties of this committee:
Affirmative votes received 147
Negative votes received 3

Amendment to By-laws, Article IV, Sec. 4, pertaining to admission to the Society:
Affirmative votes received 111
Negative votes received 1

These amendment to be in force after January 1, 1908.

The Secretary was instructed by the Board of Direction to have printed and sent out to all the members a copy of the Constitution and By-laws so amended.

The Secretary also announced the recent death on November 17th of two Active members of the Society:

Prof. Storm Bull, of Madison, Wis.
Mr. Irving Parker, of Chicago.

Mr. P. Junkersfeld introduced a resolution that the Chair appoint Committees for memorials of these late members of the Society for publication in the Journal.

There being no further business before the Society, the President introduced Mr. George B. Springer, M.W.S.E., who read his paper on "Tunnels under the Chicago River for Electric Cables." The paper was illustrated by lantern slides.

Discussion followed from President Abbott, J. W. Alvord, W. B. Ewing, C. C. Saner, P. Junkersfeld. W. H. Finley, D. W. Roper and a closure by Mr. Springer.

The meeting adjourned at 10 o'clock.

EXTRA MEETING, December 18, 1907.

An extra meeting of the Society (No. 620) was held Wednesday evening, December 18th.

The meeting was called to order at 8:20 p. m. with President Abbott in the Chair and about 84 members and guests present.

The Secretary announced the death of an Active member of the Society—Mr. William S. Love, of New York. Mr. Clayton O. Billow offered a resolution that the Chair appoint a Committee to prepare a memorial for publication, in the usual manner.

The President then introduced Mr. A. Bement, M.W.S.E., the author of the paper for the evening—"Some results due to improvement in Boiler and Furnace design,"—and called attention to the tremendous waste of coal consumed in industrial establishments because of inefficiency in steam generating apparatus. Mr. Bement read his paper which had been printed and sent out in advance. Letters in discussion of the subject were read by the Secretary from: Mr. W. J. Green, Cedar Rapids, Iowa; Mr. G. H. Barrus, Boston, Mass.; Mr. Wm. Kent, Syracuse, N. Y.; Professors L P. Breckenridge and C. S. McGovney of the University of Illinois, Urbana.

Many other letters had been received, but were not read for lack of time. Oral discussion followed from Messrs. Bryden, Chauvet, W. J. Williams, Harrington, Dr. W. A. Evans, Kuss, Osborn, Randall, Pennock, McDonald and Popenhusen.

The meeting adjourned about 11 p. m.

J. H. Warder, *Secretary.*

MINUTES OF THE ELECTRICAL SECTION, November 8, 1907.

A regular meeting of the Electrical Section (No. 26) and an extra meeting of the Society (No. 616) was held Friday evening, November 8, 1907.

The meeting was called to order at 8:15 p. m. with Mr. D. W. Roper, Vice-Chairman of the Section, presiding and about 65 members and guests present.

The Minutes of the meetings of the Section, held October 11th and 25th, were read and approved.

There being no further business to bring before the meeting Mr. A. V. Allen, representing Mr. W. D'A Ryan of the General Electric Co., was introduced, who addressed the meeting on "The Color Values of Artificial Lights." The address was illustrated by apparatus and lantern slides. The color value of four ifferent sources of illumination was practically shown by the installation of four booths with different methods of interior illumination; as an inverted incandescent gas mantle, a Nernst lamp, an enclosed arc lamp, and a group of ordinary bare incandescent filament lamps. These were suspended from the ceiling of the separate booths and below were placed an array of printed cloths of various colors. An inspection of these, which were identical for each of the four exhibits, showed the difference in the color value of these different sources of light.

Discussion followed from Messrs. J. R. Cravath, B. E. Semple, L. Friedmann, Charles H. Davis, A. L. Eustice, J. H. Warder, D. W. Roper, Jas. J. Sorber, A. C. Morrison and A. V. Allen.

A vote of thanks was tendered Mr. Allen for his interesting address.

The meeting adjourned about 10:30 p. m.

MINUTES OF ELECTRICAL SECTION, December 13, 1907.

A regular meeting of the Electrical Section (No. 27)—(No. 619 of the Society) was held Friday evening, December 13, 1907.

The meeting was called to order about 8:20 p. m. with Mr. K. B. Miller, Member of the Executive Committee, in the Chair, and about 100 members and guests present.

The Minutes of the meeting of November 8th. were read and approved.

Mr. D. W. Roper, M.W.S.E., was then introduced who read his paper describing "A few unusual burn-outs in underground cables," which was illustrated by a number of lantern slides and samples of burned cables and clay conduits.

Discussion followed from the Chairman and Messrs. W. L. Abbott, P. Junkersfeld, E. N. Lake, R. F. Schuchardt, G. H. Lukes, Morgan Brooks, with a closure by Mr. Roper.

The meeting adjourned about 10:15 p. m.

J. H. Warder, *Secretary.*

BOOK REVIEWS

Plane Surveying: A text book and pocket manual by John Clayton Tracy C. E., Assistant Professor of Structural Engineering, Sheffield Scientific School of Yale University. John Wiley & Sons, New York, 1907. 794 pages, 7 in. by 4¼. limp leather. First Edition. Price $3.00.

This work is divided into three subdivision. Part No. 1 contains 28 chapters of 360 pages and covers Field Work. Part No. 2, 15 chapters of 176 pages is on office work, and Part No. 3, 4 chapters of 83 pages is devoted to surveying instruments. An appendix of 18 pages follows, in which the methods of determining a Meridian by Solar observation are outlined and 126 pages of tables, 18 in number, complete the volume. There is an index of chapters and a table of contents by chapters in the beginning of the book and a complete alphabetical index follows the text. The tables are also preceded by an index.

The Author's plan, as explained in the preface of the work, was to produce a Text Book and Pocket Manual combined, and the scope of the work, was not to cover the whole field of surveying, but to treat thoroughly of fundamental principles and methods. This he has succeeded in doing well. The basis of the work was systematic note keeping by the author and his assistant instructors, of the questions asked, mistakes made and difficulties encountered by students in successive classes in field surveying. From these notes, a class manual was prepared some five years ago from which has grown by yearly corrections and additions, the work which is now offered to the profession.

The Author makes acknowledgement to Prof. Ives and Hilts, Merriam and Brooks, Searles, and Mr. Carhart for ten of the eighteen tables in the work, to Mr. Reinhardt of the *Engineering News* for extracts from his work in the Author's chapter on Lettering and Field Notes, and similar acknowledgment is made to Prof. Sherman of the Ohio State University. To Prof. I. O. Baker, is accredited suggestions for portions of the chapters on errors and the construction, use and adjustment of instruments.

The work as a whole, however, is the result of fifteen years of accumulated knowledge obtained by teaching, experiment and research on the part of the author, and while he is a theorist he is also practical and the work is very well balanced between its technical and practical sides.

The subject has been treated as a science, in a scientific and logical way, and while a great deal of stress has been laid on some very ordinary details of practice, it is the ordinary things which are usually most important and this cannot be impressed too strongly on the student. The surveyor will find in this work the principles underlying the solution of most of the problems confronting him written in a clear and concise manner, and as a rule, these principles are supplemented by special applications and practical illustrations.

The chapter on errors, their relative importance and probable value and final adjustment is good, as are also the special chapters on errors in lineal measurements, errors in angular measurement, and errors in leveling. The chapter on field notes will be found of value to old surveyors as well as students and the chapter on special work with the transit and level and on stadia and plane table surveys deserve special mention.

The Author's chapter on the determination of a meridian is devoted wholly to the method of observation on Polaris while the method of solar observation has been placed in the appendix for reference, if required, by students in connection with a course in field astromony, or by the practicing surveyor, preferring this method.

Office work is treated with great thoroughness, and the chapters on this subject would make a good manual for a drafting room.

The mechanical features of the book can hardly be improved upon. The paper is of the best and type face and illustrations clear. In the opinion of the reviewer, the author has produced a work which as a manual is the best which we now have on this subject. G. H. H.

TABLES OF QUANTITIES FOR PRELIMINARY ESTIMATES, by E. F. Hauch and P. D. Rice. 4¼ by 6½ ins.; pp. 92. Cloth. Price $1.25 net, John Wiley & Sons, New York. 1907.

This is a small handy book, written particularly for use in the field by railroad engineers. The tables are arranged for ready reference to assist in the computations of quantities in cubic yards of embankments. The tables are for use with prismoids of the unit length of 100 feet, and for varying width of roadbeds from 12 ft. to 32 ft. inclusive, and also for a width of 35 ft. The side slopes also vary from ¾ to 1, to 1½ to 1, while the results are for different heights of prismoid, from 0 to 50 ft. Supplemental tables for calculating the quantities in the toe slopes for the same set of widths of roadbed and the same heights—1 to 50 ft.—are given. Another table gives the value of cubic yards, based on the sum of end areas, with the same unit length of 100 ft. There is also an "Acreage Table" for a Right of Way of 100 ft. There are a couple of conversion tables, giving the reduction to feet of Gunter's chains, units up to 80 and decimals, and a reciprocal table of feet and decimals reduced to decimals of a Gunter's chain.

The paper and typography are excellent. W.

ELECTRO-ANALYSIS, by Edgar F. Smith, Professor of Chemistry, University of Pennsylvania. 4th edition, revised and enlarged and with forty-two illustrations. pp. 336 including index; 5½ by 7½ ins. Flex. Mor. Price $2.50 net. Philadelphia, P. Blakiston's Son & Co. 1907.

This book treats of the analysis of chemical compounds by the decomposing action of an electric current and which is of the more recent evolutions of the "New Chemistry." The decomposition of solutions of metallic salts by electric action have been long known and practiced in the art of electro-deposition of metals, as the coating of iron and other metals with copper; in silver and gold plating, etc. Such depositions had been determined or discovered in an empirical way, and it is a branch of business that has been largely developed within a comparatively recent time. But the procedure was hardly scientific, at least many engaged in this work simply had their own or other's experience and rules to follow to obtain results. In such operations they used known chemical compounds, which by certain known procedure resulted in obtaining a coating of some special metal, of greater or less thickness, on the object to be coated.

But in this book instructions are given of "the why and wherefore" and the procedure by which can be determined the amount present of some special metal in an unknown compound—an *analysis* in other words. The force or intensity and amount of electric energy, must be known and the manipulations to be followed to secure the desired results, are clearly set forth. The introduction of mechanical aids to assist in the electrolytic disassociaton of the metals in the compound, as agitation by means of rotating the cathode or anode, is of considerable importance. The author shows by various illustrations how this has been done by one or another investigator. The shortening of the time in making such analysis is of great value, in a commercial way.

The first part of the book discusses the sources of the electric current, the reduction of the same by various forms of rheostats, the measurements of the current, etc., followed by a historical sketch and theoretical consideration, closing with a consideration of using a mercurral cathode. The "Special Part" follows, on the determination of the halogens and of nitric acid in the electrolytic way; special applications, a rotating anode and of a mercury cathode in analysis; oxidation by means of the electric current and finally the combustion of organic compounds. Altogether the book should be of great value to students and practitioners in chemical analysis and is well worthy of a place at the right hand in an analytical laboratory. W.

Manual of Examinations for Engineering Positions in the Service of the City of New York. Questions and Answers in 3 Volumes and 8 Parts; also, Appendixes giving Examination Papers, etc., in the Civil Service of the Federal Government (including the Panama Canal and the United States Navy), New York State, Boston, New Orleans, Chicago, etc., by Myron H. Lewis, C. E, and Milton Kempner, C. E. Published by the Engineering New Publishing Co., New York, 1906. All in one octave volume; over 700 pages; cloth. Price $5.00.

The first part of this book, of about 500 pages, is made up of several pamphlets issued from time to time to give information of the character of the examinations for admission to several grades of engineering of the Civil Service. The paging is not continuous, except for each of the several 8 parts or divisions. The Appendix, however, covering the examinations for positions in the Federal service and the service of New York State; also, the service in the cities of Boston, New Orleans, etc., is paged consecutively, which is an advantage in this part of the book. From this form of make up it is not practical to have an index to cover the whole volume, which is to be regretted. The table of contents shows that for the major part of the book the examinations, etc., is for positions under the civil service in the engineering work of New York City. This consists of an introductory giving the civil service rules relating to filing applications (for positions and examinations), of marking and rating, of eligible lists, of certification and appointment, of suspension and reinstatement, of transfer, promotion and removals.

The Questions and Answers are "3 Vols." The first relating to Axeman, Chainman and Rodman, Leveler, Transitman and Computer. The second volume relates to Assistant Engineer and the third to Draftsman and Inspector. These divisions are sub-divided into Part I—Axeman. Part II—Chainman and Rodman. Part III—Leveler. Part IV—Transitman and Computer. Volume II—Assistant Engineers are classified, whether for "Rapid Transit," "General Aqueduct, Docks, Sewers and Highways." Valume III is divided in "Draftsman and Helper" and "Inspector" of Buildings, Masonry, Street Paving, Sewers, etc.

The gathering together of all this matter relating to the requirements in engineering knowledge to command positions in the civil service results in a book which is an excellent one for a course of study review. It is very likely that there are but few practicing engineers but that would be benefitted by going over such a work as this to refresh their memories on some points of engineering knowledge. To one contemplating taking an examination for an engineering position in the civil service, it would be advisable to review the questions and work out the problems set forth in these pages. Not that on the day of examination the applicant would get the same question—that would be very unlikely, but a study of the book would show the reader where he was deficient and what subjects upon which he might be examined, it was necessary for him to go back to his course of study and refresh his memory.

The book would also be valuable to the examiners under the civil service rules in its suggestions as to the questions to be put on the examination papers. The book has many illustrations and some tables. Apart from the technics of the examinations, the introductory and explanatory remarks, showing the great number of engineering positions existing under the civil service rules, the compensation to those holding such positions, etc. makes the work an interesting one. W.

Reinforced Concrete in Factory Construction. Published by the Atlas Portland Cement, 30 Broad St., New York. Pam. 6½ by 9 ins.; 249 pages; 158 illustrations.

This book is a good deal more than merely a "trade catalogue" though published at the cost of, and in the interest of, a Portland cement manufacturing company. The text of about 150 pages is good reading for those interested in concrete building construction.

Factory Construction, is the subject of Chap. I, while Design and Construction is the title of Chap. II, which includes specifications for cement and materials including the aggregate, waters, reinforcing steel, proportions, mixing, etc., design of foundations, floor systems, columns, walls, roofs, etc. In Chap. III the subject of aggregates is well discussed, and then in succeeding chapters are described sundry notable buildings of concrete construction; some ten different buildings being described with copious illustrations. Details of construction are further enlarged upon in Chap. XIV, describing with illustrations, various systems of reinforcement. Following these under the heading of Miscellaneous Buildings are 25 full page illustrations (half-tones) of exterior and interior views of various buildings completed or in process of construction, which are instructve and show the wide range of possibilities of building construction in concrete. Some 17 letters of commendation of Atlas Portland Cement are introduced in conclusion of the book. Notwithstanding the advertising character of the publication the book is well worth a place in an Engineer's library for the intrinsic value of the first part of the book, dealing with practical instructions on this subject, which has been prepared by Mr. Sanford E. Thompson, Assoc. M. Am. Soc. C. E. and joint author of that valued text-book "Concrete Plain and Reinforced."

The publishers advertise that other similar handbooks have been published by them, as "Concrete Construction about the Home and on the Farm," "Concrete Cottages" and "Concrete Country Residences." W.

TRADE PUBLICATIONS.

Steel Coal Tipples: Wisconsin Bridge & Iron Co., Andrews Allen, Contracting Engineer, 1127 Monadnock Block, Chicago. Catalogue; stiff paper cover of artistic design 12 by 9 ins.; illustrated.

This catalogue contains 20 plates, printed on heavy, glossed paper, showing various styles of steel coal tipples, as designed and built by the Wisconsin Bridge & Iron Co. These designs have been carefully worked out—and have proved well adapted to the several locations.

Elevating and Conveying Machinery: The Jeffrey Mfg. Co., Columbus, O. 1907. Catalogue D. paper; 9 by 6 ins.; pp. 56; many illustrations.

This catalogue illustrates and describes coal and ashes handling machinery of many power plants throughout the country. It is of value to mechanical engineers concerned with power plants, showing what labor saving appliances are available.

Rock Excavations Sullivan Machinery Co., Railway Exchange, Chicago. 1907. Catalogue No. 60, second edition; paper; 9 by 6 ins.; pp. 79; many illustrations.

In this catalogue the use and advantages of Rock Drills in the excavation of rock by machinery, under various conditions and for different purposes, are set forth and illustrated. There is much in the text and illustrations, that is informing and should be of interest to engineers concerned in rock excavation.

TRACK APPLIANCES: Cook's Standard Tool Co., Kalamazoo, Mich. 1907. Catalogue; paper; 9 by 6 ins.; pp. 16; illustrated.

A booklet of information of modern methods of maintaining track.

WELDED PIPES National Tube Co., Pittsburg, Pa. 1907. Catalogue; paper; 9 by 6 ins.; pp. 31; illustrated.

This catalogue illustrates and describes the progressive operations of the manufacture of modern welded pipe, from ore to finished product.

WATER FILTRATION: Loomis Manning Filter Co., Philadelphia. 1907. Catalogue; paper; 9 by 6 ins.; pp. 68; illustrated.

Illustrates and explains methods of, and means for, producing pure water as developed by mechanical appliances of the most advanced type for filtering waters, and for washing and perfectly cleansing filter beds. The apparatus is particularly adapted for small plants—as Hotels, Public Institutions, Private Residences and the like.

LIFTING MAGNETS: Cutler-Hammer Clutch Co., Milwaukee. 1907. Catalogue; paper; 8¼ by 5 ins.; pp. 32; illustrated.

This pamphlet contains a number of full page illustrations, showing lifting magnets handling pig iron, steel stampings, castings, scrap and other material, together with diagrams, data on current consumption, information on lifting capacity of magnets, etc. A new cable take-up device is also shown and described.

GAS ENGINES: Lazier Gas Engine Co., Buffalo, N. Y. Catalogue; stiff folding paper cover; 10¾ by 7½ ins.; pp. 12; illustrated.

This catalogue relates to the Lazier vertical gas engines, multiple cylinder type, for general power and lighting service, designed to operate on illuminating gas, natural gas, and producer gas.

In connection with the catalogue are six blue prints, showing, front view of assembled engine, end view of assembled engine, dissected end view of engine, cross section front view, dissected view of igniters, etc.

STEAM TURBINES: B. F. Sturtevant Co., Hyde Park, Mass. Bulletin No. 15; stiff paper; 9 by 6½ ins.; pp. 16; illustrated.

This turbine is especially adapted to fan systems of heating and ventilating public buildings. It is said to be "superior to the reciprocating engine because of its simplicity, durability,, freedom from noise or vibration and absence of governor belts." The buckets are cut in the solid wheel (and therefore indestructible) and the low speed, are featurs of special advantage.

WESTERN BLUE BOOK: Milton E. Lowitz Publishing Co., Chicago. 1907. Cloth bound volume 10½ by 8 ins.; pp. 710. Price $5.00.

This is the eighteenth year of the publication of the "Western Blue Book and Buyer's Reference," and contains a classified list of architects, engineers, contractors and manufacturers.

SEWAGE PURIFICATION AND DISPOSAL, WITHOUT SEWERS: House-Sewage Disposal Co., Chicago. Catalogue; paper; 7 by 10 ins.; 16 pp.; illustrated.

This booklet describes the Ashley methods of the purifying and disposing by the natural forces of septicization and enforced underground nitrification of domestic sewage from isolated residences, private or public institutions, factories, etc. It contains extracts from leading Biologists and Sanitary Engineers of this country and foreign countries, testimonials, and paragraphs directed to prospective users.

The subject appeals directly to those who desire to equip their homes or buildings with modern plumbing conveniences in localities having no sewer service.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for October, 1907, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

David Ross, Sec'y. Bureau of Labor Statistics, Springfield, Ill. 25th Annual Coal Report of Ill. Bureau of Labor Statistics, 1906. Cloth

John Wiley & Sons, New York. "Tables of Quantities for Preliminary Estimates," by E. F. Hauch and P. D. Rice, 1907. Cloth.
"Plane Surveying,"—A Text-book and Pocket Manual by J. C. Tracy, 1907. Leather.

Scientific Publishing Co., Manchester, England. "Fowler's Mechanical Engineer's Pocket Book," 1908. Leather.

P. Blakiston's Son & Co., Philadelphia. "Electro Analysis," by Edgar F. Smith, 1907. Leather.

Purdue University, Lafayette, Ind. Announcement of 20th Winter School of Agriculture, October, 1907. Pamphlet.

George M. Wisner, M.W.S.E., Chicago. "Disposal of Sewage from Calumet Div. of Sanitary District of Chicago," by Rudolph Hering, October, 1907. Pamphlet.

Clemens Herschel, New York. "The Venturi Water Meter," 1907. Pamphlet.

E. E. R. Tratman, M.W.S.E., Chicago. Water Supply and Irrigation Papers, Nos. 198, 202, 207, 209 and 210. Pamphlets.
Proc. Association of Railway Supts. of Bridges and Buildings, 1906. Pamphlet.
Bul. International Railway Congress, August, 1907. Pamphlet.
Railway Auto Car Co., New York, "Ganz System, Self-propelled cars for railways." Pamphlet.

P. M. Chamberlain, Chicago. Miscellaneous papers, etc. 48 Pamphlets.

Illinois-Vicksburg Military Park Commission, Col. C. R. E. Koch, Sec'y., Chicago. "Illinois at Vicksburg." 1907. Cloth.

Michigan State Board of Health, Lansing. 34th Annual Report, Mich. State Board of Health, 1906. Cloth.

New Jersey State Board of Health, Trenton. Cir. 118, "Public Health Laws," 1907. Pamphlet.

Canadian Mining Journal, Toronto, Ont. "The Ontario Meeting of American Institute of Mining Engineers," 1907. Pamphlet.

Lewis Institute, Chicago. Register 1906-7; Alumni Bulletin, July, 1907.

Mass. State Board of Health. 38th Annual Report, 1906. Cloth.

R. C. Huston, M.W.S.E., Louisville, Ky. "Report, The Hattiesburg, Miss., Traction Co.," 1907. Leather.

The Macmillan Co., New York. "The Metric and British Systems of Weights, Measures and Coinage," by F. Mollwo Perkin, Ph.D., 1907.

University of Illinois, Champaign, Ill. "The Alumni Quarterly, July, 1907."
Bul. 14, Tests of Reinforced Concrete Beams, Series of 1906, by A. N. Talbot. Pamphlet.

Milton E. Lowitz Publishing Co., Chicago. "The Western Blue Book and Buyers Reference," 1907. Cloth.

W. H. Bixby, M.W.S.E., Chicago. "Report upon the Improvement of Chicago and Calumet Harbors," etc., 1907. Pamphlet.

C. L. Strobel, M.W.S.E., Chicago. "The History of the First National Bank of Chicago," by Henry C. Morris, 1902. Cloth.

EXCHANGES.

Institution of Electrical Engineers, London. Proc. Mar., May, 1907. No. 2. Pamphlet.

American Institute of Electrical Engineers. Transactions of the Institute for 1906. Vol. 25. Cloth.

North-east Coast Institution of Engineers and Shipbuilders. Transactions of the Institution for 1906-7. Vol. 23. Half-leather.

Wisconsin Geological and Natural History Survey. "The Geology of North Central Wisconsin, Wiedman," 1907. Bul. No. XVI. Cloth.
"The Abandoned Shore-Lines of eastern Wisconsin, Goldthwait," 1907. Bul. XVII. Cloth.
"Rural Highways of Wisconsin, W. O. Hotchkiss," 1906. Bul. XVIII. Pamphlet.

Illinois State Geological Survey. Cir. No. 2. "Mineral Production of Illinois in 1906, Van Horn." Pamphlet.

Geological Survey of Canada. Various Reports of Geological Survey. 30 pamphlets.

Smithsonian Institution, Washington. Annual Report for 1906. Cloth.

Master Car Builders' Assc'n., Chicago. 41st Annual Report of Assc'n., 1907. Half-leather.

Railway Signal Association, Bethlehem, Pa. No. 5, Vol. 10, Sept. 10, 1907. Pamphlets.

Ohio State Highway Dept., Columbus. Bul. No. 9, Proposed Amended State Aid Law, by S. Huston. Pamphlet.

Royal Society of New South Wales. Journal and Proceedings for 1906. Vol. XL. Pamphlet.

American Water Works Assc'n. Proc. 37th annual convention, 1907. Cloth.

Iowa Engineering Society, Iowa City, Ia. Proc. 19th Annual Meeting, 1907. Pamphlet.

Western Australia Geographical Survey. Bul. No. 26, 1907. Pamphlet.

Institution of Civil Engineers, London. Minutes of Proceedings. Part III, 1906-7. Pamphlet.

GOVERNMENT PUBLICATIONS.

U. S. Geological Survey, Dept. of Interior. Pamphlets.
Production of Graphite in 1906, by G. O. Smith.
Production of Coal in 1906 by E. W. Parker.
Production of Lime and Sand-lime Brick in 1906, E. C. Eckel.
Production of Platinum in 1906, by Day.
Production of Mineral Paints in 1906, by Eckel.
Production of Sulphur and Pyrite in 1906, Day.
Production of Abrasive Materials in 1906, Sterrett.
Production of Iron Ores and Iron Products in 1906. Eckel.
Production of Petroleum in 1906. Griswold.
Production of Manganese Ores in 1906. E. C. Eckel.
Production of Antimony, Arsenic, Bismuth & Selenium in 1906, Hess.
Production of Natural Gas in 1906. B. Hill.
Production of Quicksilver in 1906. Boutwell.
Production of Lead in 1905. Boutwell.
Bul. 304. Oil and Gas Fields of Greene Co., Pa., Stone & Clapp.
Bul. 311. The Green Schists and Associated Granites and Porphyries of Rhode Island.
Bull. 313. The Granites of Maine.
Bul. 317. Preliminary Report on the Santa Maria Oil District, Santa Barbara County, Cal. Arnold & Anderson.
Bul. 318. Geology of Oil and Gas Fields in Steubenville, Burgettstown and Claysville Quadrangles, Ohio, West Virginia and Pennsylvania.

  - Bul. 320. The Downtown District of Leadville, Colo.
  - Bul. 323. Experimental Work Conducted in the Chemical Laboratory of the U. S. Fuel-Testing Plant at St. Louis. Lord.
  - Bul. 324. The San Francisco Earthquake and Fire in April, 1906, and their effects on structures and structural material.
  - Professional paper No. 53. Geology and Water Resources of the Bighorn Basin, Wyoming, by C. A. Fisher.
  - The Manufacture of Coke in 1906, E. W. Parker.
  - Statistics of the Clay-working Industries in the U. S. in 1906. Middleton.
  - A study of Four Hundred Steaming Tests made at Fuel-Testing Plant, St. Louis, Mo. Breckenridge. Bul. 325.
- U. S. Dept. of Commerce and Labor, Bureau of Census. Pamphlets.
  - Census of Manufacturers, 1905:
  - Bul. 81. Shipbuilding.
  - Bul. 82. Musical Instruments, etc.
  - Bul. 83. Slaughtering and Meat Packing, manufactured ice and salt.
  - Bul. 84. Carriages and Wagons, and the Steam and Street Railroad Car Industry.
  - Bul. 85. Pens, Pencils, Buttons, Needles, Pins, etc.
  - Bul. 86. Copper, Lead and Zinc.
  - Bul. 87. Tobacco.
  - Bul. 88. Power employed in manufactures.
  - Bul. 89. Population of Oklahoma and Indian Territory, 1907.
  - Bul. 90. Supply and Distribution of Cotton.
  - Statistics of Cities having a population of over 30,000. 1905.
  - Special Reports. Prisoners and Juvenile Delinquents in Institutions, 1904.
- U. S Dept. of Agriculture, Forest Service. Pamphlets.
  - Cir. 98. Quantity and character of creosote in well-preserved timbers, by Gellert Alleman.
  - Cir. 111. Prolonging the Life of Mine Timbers, by J. M. Nelson, Jr.
  - Cir. 114. Wood Distillation, by W. C. Geer. Nov., 1907.
  - Cir. 115. Strength of Structural Timber—second progress report, by W. K. Hatt.
  - Cir. 117. Preservative Treatment of Fence Posts, Weiss.
  - Cir. 119. Consumption of Tanbark and Tanning Extract in 1906.
  - Cir. 120. Consumption of Pulpwood in 1906.
  - Cir. 121. Wood Used for Distillation in 1906.
  - Cir. 123. Production of Slack Cooperage Stock in 1906.
  - Cir. 124. Consumption of Cross-ties in 1906.
  - Cir. 126. Forest Tables—Lodgepole Pine, Ziegler.
  - Cir. 129. The Drain upon the Forests, R. S. Kellogg.
- U. S. Commissioner of Education. Report of Commissioner for 1906. Vol. I. Cloth.

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